

DESCRIPTION

OPTICALLY ACTIVE QUATERNARY AMMONIUM SALT, PRODUCTION METHOD THEREOF, AND METHOD FOR PRODUCING OPTICALLY ACTIVE α -AMINO 5 ACID DERIVATIVE USING THE QUATERNARY AMMONIUM SALT

TECHNICAL FIELD

[0001]

The present invention relates to a novel axially chiral, 10 optically active spiro-quaternary ammonium salt and a production method thereof, as well as to an intermediate for use in the production of such an ammonium salt and a production method thereof. The present invention further relates to a method for stereoselectively producing an 15 optically active α -amino acid derivative, a useful intermediate for the synthesis of pharmaceutical or agrochemical products, by using the ammonium salt as a phase transfer catalyst.

[0002]

20 The present invention also relates to a fluorine-containing optically active quaternary ammonium salt and a production method thereof, as well as to an intermediate useful in the production of such a salt and a production method thereof. The present invention still further relates to 25 a method for stereoselectively producing an optically active

α -amino acid derivative, a useful intermediate for the synthesis of pharmaceutical or agrochemical products, by using the fluorine-containing ammonium salt as a phase transfer catalyst, as well as to a method for recovering such a salt.

5 More specifically, the present invention relates to a method for recovering a fluorine-containing optically active quaternary ammonium salt by using an organic solvent with all hydrogen atoms substituted with fluorine atoms (i.e., fluorous solvent).

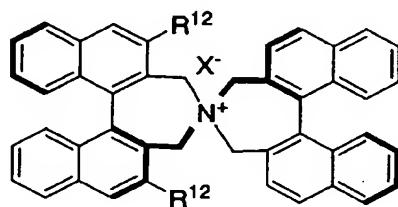
10

BACKGROUND ART

[0003]

As far as the background of the present invention is concerned, optically active spiro-quaternary ammonium salts 15 (A) through (N), which are collectively represented by the following formula (15), are known:

[0004]



(15)

[0005]

20 where

R^{12} = a hydrogen atom and X^- = a bromide ion (Compound (A));

R^{12} = a phenyl group and X^- = a bromide ion (Compound (B));

R¹² = a β -naphthyl group and X⁻ = a bromide ion (Compound (C));

R¹² = a 3,4,5-trifluorophenyl group and X⁻ = a bromide ion (Compound (D));

R¹² = a 3,5-bistrifluoromethylphenyl group and X⁻ = a bromide ion (Compound (E));

R¹² = a 3,5-bis(3,5-bistrifluoromethylphenyl)phenyl group and X⁻ = a bromide ion (Compound (F));

R¹² = a 3,5-bis-*tert*-butylphenyl and X⁻ = a bromide ion (Compound (G));

R¹² = a 3,5-bis(3,5-bis-*tert*-butylphenyl)phenyl group and X⁻ = a bromide ion (Compound (H));

R¹² = a β -naphthyl group and X⁻ = a thiocyanic acid ion (Compound (I));

R¹² = a β -naphthyl group and X⁻ = a hydrogen sulfate ion (Compound (J));

R¹² = a 3,5-bistrifluoromethylphenyl group and X⁻ = a thiocyanic acid ion (Compound (K));

R¹² = a 3,5-bistrifluoromethylphenyl group and X⁻ = a hydrogen sulfate ion (Compound (L));

R¹² = a 3,4,5-trifluorophenyl group and X⁻ = a thiocyanic acid ion (Compound (M)); and

R¹² = a 3,4,5-trifluorophenyl group and X⁻ = a hydrogen sulfate ion (Compound (N)) (See, for example, Patent Article No. 1 for Compounds (A) through (D), Non-Patent Article No. 1 for Compounds (E) and (F), Non-Patent Article No. 2 for Compounds

(G) and (H), and Patent Article No. 2 for Compounds (I) through (N)).

[0006]

Also, optically active spiro-quaternary ammonium salts 5 (O) and (P), which are collectively represented by the following formula (16), are known:

[0007]



[0008]

10 where

R^{13} = a hydrogen atom and X^- = a bromide ion (Compound (O));

and

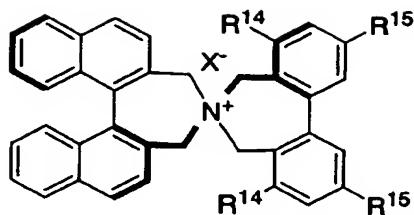
R^{13} = a β -naphthyl group and X^- = a bromide ion (Compound (P))

(See Patent Article No. 3).

15 [0009]

Furthermore, optically active spiro-quaternary ammonium salts (Q), (R), and (S), which are collectively represented by the following formula (17), are known:

[0010]



(17)

[0011]

where

R^{14} = a β -naphthyl group, R^{15} = a hydrogen atom, and X^- = a 5 bromide ion (Compound (Q));

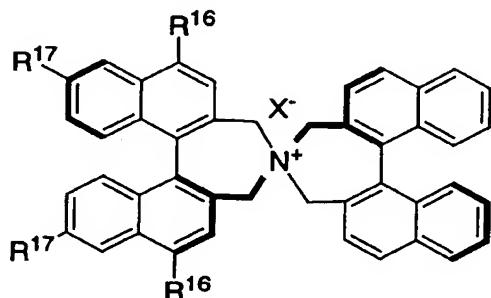
R^{14} = a 3,5-diphenylphenyl, R^{15} = a hydrogen atom, and X^- = a bromide ion (Compound (R)); and

R^{14} = a 3,5-diphenylphenyl group, R^{15} = a phenyl group, and X^- = a bromide ion (Compound (S)) (See Patent Article No. 3).

10 [0012]

Still further, optically active spiro-quaternary ammonium salts (T), (U), and (V), which are collectively represented by the following formula (18), are known:

[0013]



(18)

15

[0014]

where

R¹⁶ = R¹⁷ = a phenyl group and X⁻ = a bromide ion (Compound (T));

R¹⁶ = a phenyl group, R¹⁷ = a hydrogen atom, and X⁻ = a bromide ion (Compound (U)); and

5 R¹⁶ = R¹⁷ = a 3,5-diphenylphenyl group and X⁻ = a bromide ion (Compound (V)) (See Non-Patent Article No. 3).

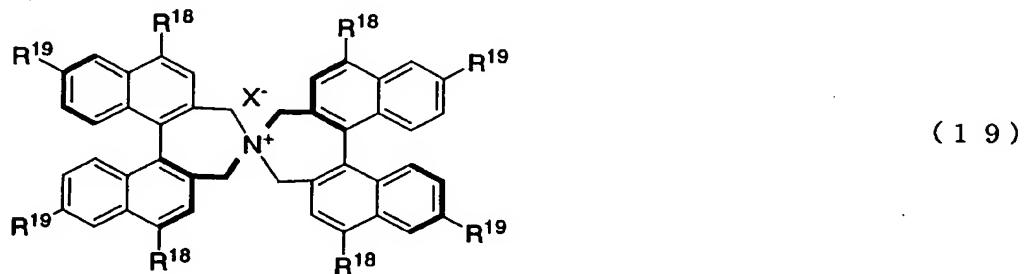
[0015]

Some of Compounds (A) through (V), for example Compound (D), are highly reactive and stereoselective. Nonetheless, the 10 asymmetric structure of these compounds results in as many as 13 to 16 different steps involved in the synthesis of the catalysts when commercially available optically active 1,1-bi-2-naphthol is used as the starting material.

[0016]

15 Still further, optically active spiro-quaternary ammonium salts (W), (X), (Y), and (Z), which are collectively represented by the following formula (19), are known:

[0017]



20 [0018]

where

$R^{18} = R^{19} =$ a phenyl group and X^- = a bromide ion (Compound (W));

R^{18} = a phenyl group, R^{19} = a hydrogen atom, and X^- = a bromide ion (Compound (X));

5 $R^{18} = R^{19}$ = a 3,5-diphenylphenyl group and X^- = a bromide ion (Compound (Y)); and

R^{18} = a 3,5-diphenylphenyl group, R^{19} = a hydrogen atom, and X^- = a bromide ion (Compound (Z)) (See, for example, Non-Patent Article No. 4). Since the two binaphthyl structures in these 10 compounds are identical to each other, the number of the steps involved in the synthesis of these catalysts is decreased to 8 to 11 steps.

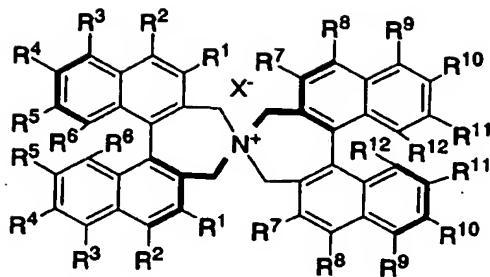
[0019]

In terms of catalytic performance, these catalysts show 15 high reactivity and high selectivity of 90% or above toward certain substrates when used in the asymmetric alkylation of glycine derivatives as described in the non-patent article. However, the catalysts have been proved to show decreased 20 reactivity and selectivity toward some substrates such as ethyl iodide.

[0020]

Of all the compounds represented by the following formula (1):

[0021]



(1)

[0022]

only those in which the substituents on the aromatic rings are either hydrogen or carbon atoms are known. In addition, no 5 compounds are known that are represented by the formula (1) with silicon atoms or silicon-containing compounds directly bound to the aromatic rings.

[0023]

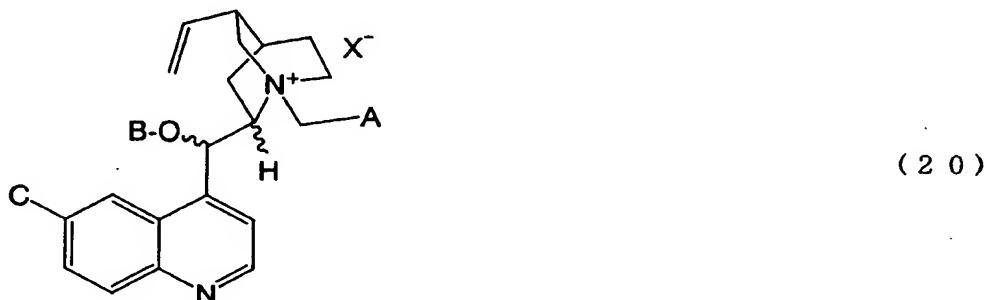
When optically active quaternary ammonium salts are used 10 as phase-transfer catalysts in the production of optically active α -amino acid derivatives, the catalysts may be recovered afterwards for recycle. In one technique, this is done by neutralizing the aqueous phase with an acid after separation, extracting the aqueous phase with an organic 15 solvent, and then purifying the extract by silica gel column chromatography (Non-Patent Article No. 5). While this technique is advantageous in that the activity of the recycled catalysts is retained, the recovery of the catalyst is only 72% and the technique involves many steps. For this reason, 20 improvement in the recovery of the catalyst is required. Also, the process for recovering catalysts must be simplified enough

to be used in industrial applications.

[0024]

A much simpler approach to recover catalysts involves the use of a compound represented by the following formula (20):

5 [0025]



[0026]

This compound comprises an ammonium salt derivative of an optically active alkaloid (e.g., quinine, quinidine, 10 cinchonine, and cinchonidine) bound to a polymer such as polystyrene and polyethylene glycol and is suitable for use as a chiral phase-transfer catalyst in the production of optically active α -amino acid derivatives (See Non-Patent Articles 6-8 for examples in which the polymer is introduced 15 at the position 'A', Non-Patent Article 7 for an example in which the polymer is introduced at the position 'B', and Non-Patent Article No. 9 for an example in which the polymer is introduced at the position 'C'.).

[0027]

20 However, introduction of the polymer moiety may result in a significant decrease in the selectivity of the catalyst (See,

for example, Non-Patent Article No. 9). Even many of the catalysts that retain high stereoselectivity of 90% ee or above have not been shown to retain the catalytic performance when recycled following recovery (See, for example, Non-Patent 5 Articles 7 and 8). Although no data is presented, only one example of practically recyclable catalysts is reported. In this case, a significant reduction of the selectivity is also experienced in this example when a different substrate is used (See, for example, Non-Patent Article No. 6).

10 [0028]

As optically active quaternary ammonium salts in which the backbone structure contains a fluorine atom as a C-F bond, alkaloid derivatives incorporating a fluorine-substituted benzyl group are known (See, for example, Non-Patent Articles 15 10 and 11). Also, optically active ammonium catalysts having such substituents as a 4-fluorophenyl group and a 3,4,5-trifluorophenyl group (See, for example, Non-Patent Article No. 12), a 3,5-bis(trifluoromethyl)phenyl group or a 3,5-bis{3,5-bis(trifluoromethyl)phenyl}phenyl group (See, for example, 20 Non-Patent Article No. 13) are known as optically active quaternary ammonium salt derivatives having a chiral axis originating from binaphthyl.

[0029]

However, each of these compounds contains fluorine atoms 25 in the form of 1 to 3 fluorine substituents on the benzene

ring or in the form of 1 to 8 trifluoromethyl groups: No optically active quaternary ammonium salts have been known to date that contain fluorine atoms in the form of perfluoro groups, or substituents consisting of two or more carbon atoms 5 with all the hydrogen atoms substituted with fluorine atoms.

[0030]

Different perfluoro alkyl-containing optically active asymmetric catalyst ligands are known, including axially chiral binaphthol derivatives (See, for example, Non-Patent 10 Articles No. 14-18), optically active salen derivatives (See, for example, Non-Patent Articles No. 19-22), optically active ephedrine derivatives (See, for example, Non-Patent Article No. 23), and optically active aminothiolates (See, for example, Non-Patent Article No. 24). Each of these compounds is used in 15 the synthesis of optically active compounds different from the compounds of the present invention. Attempts for recovery and recycle have been made for some of the compounds.

[0031]

However, except for the asymmetric protonation agents 20 used in stoichiometric amounts (Non-Patent Article 14), each compound has to be catalytically prepared through the formation of oxygen-metal bonds or complexes: No optically active organic catalysts are known that themselves serve as an asymmetric catalyst. In particular, no optically active 25 quaternary ammonium salts are known that contain perfluoro

alkyl groups consisting of two or more carbon atoms. Nor are any examples known of the use of the salts as asymmetric catalysts or as phase-transfer catalysts. No examples are known in which the phase transfer catalytic reaction is 5 carried out in a three-phase system consisting of organic, aqueous and fluorous phases, nor are any examples described of the use of fluorous solvents to separate/purify the salts or to recover only the catalyst from the catalyst-containing mixture remaining after the reaction. No examples are known of 10 recovering the salts to serve as catalysts in a substantially quantitative manner, nor are any examples known in which the salts are recovered in a separate phase of a fluorous solvent and the recovered salts are recycled as an asymmetric catalyst in the same reaction, and which demonstrate that the 15 performance of the catalyst as measured by the reactivity and stereoselectivity are retained.

[Patent Article No. 1] Japanese Patent Laid-Open
Publication No. 2001-48866

[Patent Article No. 2] Japanese Patent Laid-Open
20 Publication No. 2002-173492

[Patent Article No. 3] Japanese Patent Laid-Open
Publication No. 2002-326992

[Non-Patent Article No. 1] K. Maruoka et. al., Angew.
Chem. Int. Ed. 2002, 41, 4542-4544

[Non-Patent Article No. 2] K. Maruoka et. al. *Angew. Chem. Int. Ed.* 2003, 42, 579-582

[Non-Patent Article No. 3] K. Maruoka et. al., *Tetrahedron Lett.* 2003, 44, 3313-3316

5 [Non-Patent Article No. 4] K. Maruoka et. al. *Tetrahedron: Asymm.* 2003, 14(12), 1599-1602

[Non-Patent Article No. 5] K. Maruoka et. al., *Tetrahedron Lett.* 2000, 41, 8339-8342

[Non-Patent Article No. 6] R. Chinchilla et. al., *Tetrahedron: Asymm.*, 2000, 11, 3277-3281

10 [Non-Patent Article No. 7] D. Cahard et. al., *Synthesis*, 2001, 11, 1742-1746

[Non-Patent Article No. 8] D. Cahard et. al., *Tetrahedron: Asymm.*, 2001, 12, 983-986

15 [Non-Patent Article No. 9] M. Benaglia et. al., *Tetrahedron: Asymm.*, 2003, 14, 461-467

[Non-Patent Article No. 10] H. G. Park et. al., *Org. Lett.*, 2002, Vol. 4, No. 24, 4245-4248

[Non-Patent Article No. 11] B. R. Cho et. al., *J. Org. Chem.*, 1987, 52, 4752-4756

20 [Non-Patent Article No. 12] Keiji Maruoka et. al., *J. Am. Chem. Soc.*, 2003, 125, 5139-5151

[Non-Patent Article No. 13] K. Maruoka et. al., *J. Am. Chem. Soc.*, 2003, 125, 2054-2055

25 [Non-Patent Article No. 14] S. Takeuchi et. al.,

Tetrahedron, 2000, 56, 351-356

[Non-Patent Article No. 15] S. Takeuchi et. al.,

Tetrahedron, 2002, 58, 3963-3969

[Non-Patent Article No. 16] K. S. Chan et. al.,

5 Tetrahedron, 2002, 58, 3951-3961

[Non-Patent Article No. 17] D. Sinou et. al.,

Tetrahedron: Asymm., 2002, 13, 1449-1456

[Non-Patent Article No. 18] D. Sinou et. al., Chem.

Commun., 2001, 1220-1221

10 [Non-Patent Article No. 19] D. Sinou et. al., Tetrahedron, 2002, 58, 3971-3976

[Non-Patent Article No. 20] G. Pozzi et. al., Eur. J. Org.

Chem., 1999, 1947-1955

[Non-Patent Article No. 21] G. Pozzi et. al., Chem.

15 Commun., 2000, 2171-2172

[Non-Patent Article No. 22] G. Pozzi et. al., Tetrahedron, 2002, 58, 3943-3949

[Non-Patent Article No. 23] S. Takeuchi et. al.,

Tetrahedron, 2001, 57, 5565-5571

20 [Non-Patent Article No. 24] G. v. Koten et. al., Org.

Lett., 1999, Vol. 1, No. 6, 853-855

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0032]

25 In view of the above-described state of the background

art, objects of the present invention are:

- 1) to provide a novel axially chiral, optically active spiro-
quaternary ammonium salt, that when used as a phase-transfer
catalyst in the asymmetric alkylation of a glycine derivative,
5 gives a high stereoselectivity of 90% ee or above and has a
novel substituent to provide steric hindrance that allows the
salt to be applied to a broader range of substrates with high
selectivity, and in particular, to provide a compound in which
each ring of the spiro-structure has the same structure and
10 which is thus advantageous in terms of the number of steps
involved in the synthesis of the catalyst;
- 2) to provide a method for producing the salts;
- 3) to provide an intermediate for use in the production of the
salts, and a method for producing the intermediate; and
15
- 4) to provide a method for using the ammonium salts as a phase
transfer catalyst and thus stereoselectively producing an
optically active α -amino acid derivative suitable for use as
an intermediate in the synthesis of pharmaceutical or
agrochemical products.

20 Further objects of the present invention are:

- 5) to provide a novel optically active quaternary ammonium
salt, that when used as a phase-transfer catalyst in the
asymmetric alkylation of a glycine derivative, gives a high
stereoselectivity of 90% ee or above and is readily recovered
25 after the reaction;

- 6) to provide the salt that retains its catalytic performance when recycled;
- 7) to provide a method for readily recovering, separating, and purifying the salt at high yield after the reaction;
- 5 8) to provide a method for producing the salt;
- 9) to provide a method for using the salt as a phase-transfer catalyst and thus stereoselectively producing an optically active α -amino acid derivative suitable for use as an intermediate in the synthesis of pharmaceutical or
- 10 agrochemical products; and
- 10) to recover the salt used in the reaction and ensure that high catalytic performance is retained in the recycled salt.

MEANS FOR SOLVING THE PROBLEMS

[0033]

15 In an effort to address the objects 1) through 4) above, the present inventor has conducted an extensive study and found a novel axially chiral, optically active ammonium salt that incorporates a novel alkyl- or aryl-substituted silyl group as a substituent on the binaphthyl aromatic ring.

20 [0034]

In a further effort to address the objects 5) through 10) above, the present inventor has conducted extensive study and found a novel axially chiral, optically active ammonium salt that includes a perfluoro group with all hydrogen atoms 25 substituted with fluorine atoms, and such an ammonium salt,

after use as a chiral phase-transfer catalyst, can be extracted for recycle with a fluorous solvent that has all hydrogen atoms substituted with fluorine atoms. It is these findings that led to the present invention.

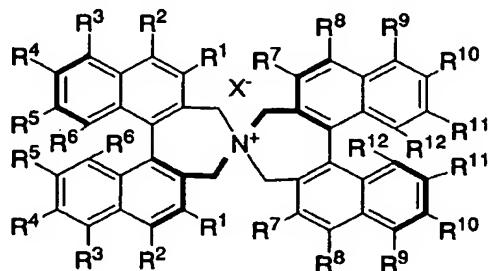
5 [0035]

Accordingly, the present invention concerns an optically active quaternary ammonium salt, a method for producing the ammonium salt, a method for producing an optically active α -amino acid derivative using the ammonium salt, and a method 10 for recovering the ammonium salt, as follows.

[0036]

[1] An optically active quaternary ammonium salt, represented by the following formula (1a):

[0037]



(1a)

15

[0038]

[wherein R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, R¹⁰, R¹¹, and R¹² are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 20 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or

cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0039]

with the proviso that at least one of R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 , R^9 , R^{10} , R^{11} , and R^{12} is a substituent represented by the following formula (2a):

[0040]



[0041]

(wherein R^{13} , R^{14} , and R^{15} are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms.);

[0042]

X^- is a fluorine ion, a chloride ion, a bromide ion, an iodide ion, a p-toluenesulfonic acid ion, a hydroxide ion, a thiocyanate ion, a hydrogen sulfate ion, a perchloric acid ion, or a hexafluorophosphoric acid ion; and the two binaphthyl moieties each have a chiral axis so that the absolute configurations of the two binaphthyl moieties are (R, R) or (S, S)].

[0043]

[2] The optically active quaternary ammonium salt according to [1] above, wherein R^1 and R^7 , R^3 and R^9 , R^4 and R^{10} , R^5 and R^{11} , and R^6 and R^{12} in the formula (1a) are in each case identical to one another; R^2 and R^8 are identical to one another and are each represented by the formula (2a); and X^- is a fluorine ion, a chloride ion, a bromide ion, an iodide ion, a p-toluenesulfonic acid ion, or a hydroxide ion.

[0044]

[3] The optically active quaternary ammonium salt according to [1] above, wherein R^1 , R^3 , R^5 , R^6 , R^7 , R^9 , R^{11} , and R^{12} in the formula (1a) are each independently a hydrogen atom; R^2 , R^4 , R^8 , and R^{10} are identical to one another and are each represented by the formula (2a); and X^- is a chloride ion, a bromide ion, an iodide ion, or a p-toluenesulfonic acid ion.

[0045]

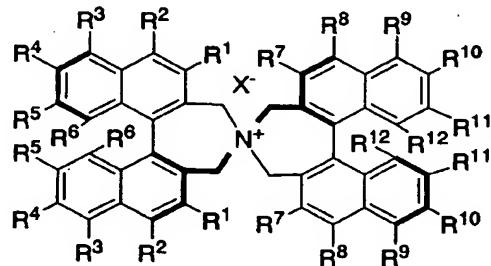
[4] The optically active quaternary ammonium salt according to [1] above, wherein in the formula (1a), R^1 and R^7 , R^3 and R^9 , R^4

and R^{10} , R^5 and R^{11} , and R^6 and R^{12} are in each case identical to one another, R^2 and R^8 are identical to one another and are each represented by the formula (2a), and X^- is a bromide ion; and R^{13} , R^{14} and R^{15} in the formula (2a) are each independently 5 a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0046]

10 [5] An optically active quaternary ammonium salt represented by the following formula (1b):

[0047]



(1 b)

[0048]

15 [wherein R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 , R^9 , R^{10} , R^{11} , and R^{12} are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 20 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic heteroalkyl group that has 3 to

18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkynyl group
5 that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, an alkoxy group that has 1 to 18 carbon atoms and may or may not be substituted with fluorine, an aryl group that has 5 to 20 carbon atoms and may or may not be substituted with fluorine, an aralkyl group that has 5 to
10 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine;

[0049]

with the proviso that at least one of R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 ,
15 R^8 , R^9 , R^{10} , R^{11} , and R^{12} is a substituent represented by the following formula (2b):

[0050]

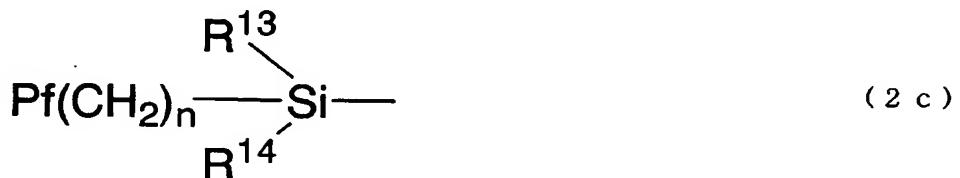
$Pf(CH_2)_n$ ————— (2b)

[0051]

20 (wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight,

branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms. n is an integer from 0 to 4.), and/or by the following formula (2c):

10 [0052]



[0053]

(wherein Pf and n are as defined in the formula (2b) above,

[0054]

15 R^{13} and R^{14} are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms,

20 an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon

atoms.);

[0055]

X⁻ is a fluoride ion, a chloride ion, a bromide ion, an iodide ion, a p-toluenesulfonic acid ion, a hydroxide ion, a thiocyanate ion, a hydrogen sulfate ion, a perchloric acid ion, or a hexafluorophosphoric acid ion; and the two binaphthyl moieties each have a chiral axis so that the absolute configurations of the two binaphthyl moieties are (R, R) or (S, S)].

10 [0056]

[6] The optically active quaternary ammonium salt according to [5] above, wherein R¹ and R⁷, R³ and R⁹, R⁴ and R¹⁰, R⁵ and R¹¹, and R⁶ and R¹² in the formula (1b) are in each case identical to one another; R² and R⁸ are identical to one another and are each represented by the formula (2a); and X⁻ is a fluorine ion, a chloride ion, a bromide ion, an iodide ion, a p-toluenesulfonic acid ion, a thiocyanate ion, a hydrogen sulfate ion, or a hydroxide ion.

[0057]

20 [7] The optically active quaternary ammonium salt according to [5] above, wherein R¹, R³, R⁵, R⁶, R⁷, R⁹, R¹¹, and R¹² in the formula (1b) are each independently a hydrogen atom; R², R⁴, R⁸, and R¹⁰ are identical to one another and are each represented by the formula (2c); and X⁻ is a chloride ion, a bromide ion, an iodide ion, or a p-toluenesulfonic acid ion.

[0058]

[8] The optically active quaternary ammonium salt according to [5] above, wherein in the formula (1b), R¹ and R⁷, R³ and R⁹, R⁴ and R¹⁰, R⁵ and R¹¹, and R⁶ and R¹² are in each case identical to 5 one another, and X⁻ is a bromide ion; and in the formula (2c), n is 2, R¹³ and R¹⁴ are each a methyl group, and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

[0059]

10 [9] An optically active binaphthyl compound represented by the following formula (3a):

[0060]



[0061]

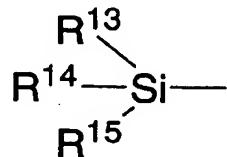
15 [wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group 20 having 3 to 18 carbon atoms, a straight, branched or cyclic

alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

5 [0062]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

[0063]



(2a)

10 [0064]

(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); X is a chlorine atom, a bromine atom, an iodine atom, or a p-toluenesulfonyloxy group; and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

[0065]

[10] The optically active binaphthyl compound according to [9] above, wherein R^1 , R^3 , R^5 , and R^6 in the formula (3a) are each independently a hydrogen atom; and R^2 and R^4 are identical to 5 one another and are each represented by the formula (2a).

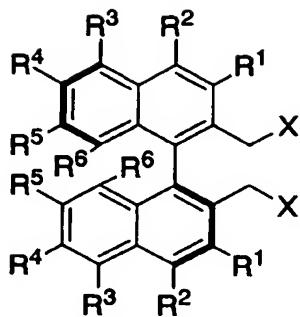
[0066]

[11] The optically active binaphthyl compound according to [9] above, wherein in the formula (3a), R^1 , R^3 , R^5 , and R^6 are each independently a hydrogen atom, R^2 and R^4 are identical to one 10 another and are each represented by the formula (2a), and X is a bromine atom; and R^{13} , R^{14} , and R^{15} in the formula (2a) are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, 15 a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0067]

[12] An optically active binaphthyl compound represented by the following formula (3b):

20 [0068]



(3b)

[0069]

[wherein R¹, R², R³, R⁴, R⁵ and R⁶ are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic heteroalkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, an alkoxy group that has 1 to 18 carbon atoms and may or may not be substituted with fluorine, an aryl group that has 5 to 20 carbon atoms and may or may not be substituted with fluorine, an aralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with

fluorine;

[0070]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2b):

5 [0071]



[0072]

(wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms

10 substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all

the hydrogen atoms substituted with fluorine atoms,

15 an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl

group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkyl

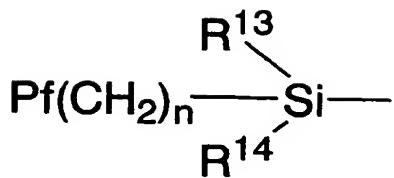
group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms,

20 atoms substituted with fluorine atoms,

[0073]

and n is an integer from 0 to 4.), and/or by the following formula (2c):

[0074]



(2c)

[0075]

(wherein Pf and n are as defined in the formula (2b) above,

[0076]

5 R¹³ and R¹⁴ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms.);

[0077]

15 X is a chlorine atom, a bromine atom, an iodine atom, or a p-toluenesulfonyloxy group; and

[0078]

the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

20 [13] The optically active binaphthyl compound according to [12] above, wherein R¹, R³, R⁵, and R⁶ in the formula (3b) are each independently a hydrogen atom; and R² and R⁴ are identical

to one another and are each represented by the formula (2c).

[0079]

[14] The optically active binaphthyl compound according to

[12] above, wherein in the formula (3b), R¹, R³, R⁵, and R⁶ are

5 each independently a hydrogen atom, R² and R⁴ are identical to
one another and are each represented by the formula (2c), and
X is a bromine atom; and in the formula (2c), n is 2, R¹³ and
R¹⁴ are each a methyl group, and Pf is an n-octyl group having
all the hydrogen atoms substituted with fluorine atoms.

10 [0080]

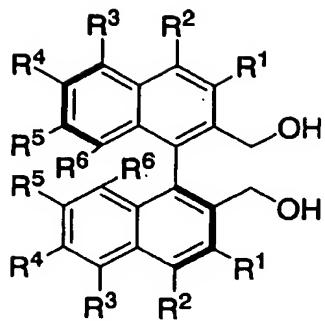
[15] A method for producing the optically active quaternary
ammonium salt according to any of [1] to [8] above represented
by the formula (1a) or (1b) in which X⁻ is a chloride ion, a
bromide ion, an iodide ion, or a p-toluenesulfonic acid ion,
15 characterized in that the optically active binaphthyl compound
according to any of claim 9 to claim 14 above represented by
the formula (3a) or (3b) is reacted with ammonia.

[0081]

[16] An optically active binaphthyl dihydroxyl compound

20 represented by the following formula (4a):

[0082]



(4 a)

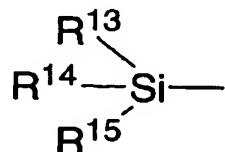
[0083]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0084]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

[0085]



(2 a)

[0086]

(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group,

an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an 5 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl 10 moiety is (R) or (S)].

[0087]

[17] The optically active binaphthyl dihydroxyl compound according to [16] above, wherein R^1 , R^3 , R^5 , and R^6 in the formula (4a) are each independently a hydrogen atom; and R^2 and 15 R^4 are identical to one another and are each represented by the formula (2a).

[0088]

[18] The optically active binaphthyl dihydroxyl compound according to [16] above, wherein in the formula (4a), R^1 , R^3 , 20 R^5 , and R^6 are each independently a hydrogen atom, and R^2 and R^4 are identical to one another and are each represented by the formula (2a); and R^{13} , R^{14} , and R^{15} in the formula (2a) are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an 25 isopropyl group, an n-butyl group, an isobutyl group, a sec-

butyl group, a *tert*-butyl group, an *n*-octyl group, and a phenyl group.

[0089]

[19] An optically active binaphthyl dihydroxyl compound 5 represented by the following formula (4b):

[0090]



[0091]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a 10 hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or 15 cyclic heteroalkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and may 20 or may not be substituted with fluorine, an alkoxy group that

has 1 to 18 carbon atoms and may or may not be substituted with fluorine, an aryl group that has 5 to 20 carbon atoms and may or may not be substituted with fluorine, an aralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine;

5 substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine;

[0092]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2b):

[0093]

$Pf(CH_2)_n$ ————— (2 b)

[0094]

(wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkyl

group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, and n is an integer from 0 to 4.), and/or by the following formula (2c):

[0095]



5

[0096]

(wherein Pf and n are as defined in the formula (2b) above,

[0097]

R¹³ and R¹⁴ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms.); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

20 [0098]

[20] The optically active binaphthyl dihydroxyl compound according to [19] above, wherein R¹, R³, R⁵, and R⁶ in the

formula (4b) are each independently a hydrogen atom; and R² and R⁴ are identical to one another and are each represented by the formula (2c).

[0099]

5 [21] The optically active binaphthyl dihydroxyl compound according to [19] claim 10 above, wherein in the formula (4b), R¹, R³, R⁵, and R⁶ are each independently a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c); and in the formula (2c), n is 2, R¹³ and 10 R¹⁴ are each a methyl group, and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

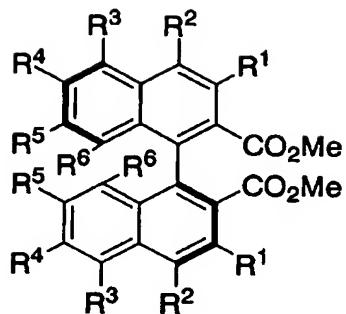
[0100]

[22] A method for producing the optically active binaphthyl compound of the formula (3a) or (3b) according to any of [9] 15 to [14], characterized in that the optically active binaphthyl dihydroxyl compound of the formula (4a) or (4b) according to any of [16] to [21] is reacted with a halogen source or p-toluenesulfonyl chloride.

[0101]

20 [23] An optically active binaphthyl diester compound represented by the following formula (5a):

[0102]



(5 a)

[0103]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

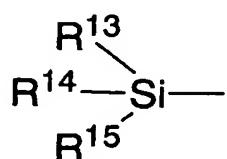
5 branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

10 having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0104]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

[0105]



(2 a)

[0106]

(wherein R^{13} , R^{14} , and R^{15} are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a 5 straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and the binaphthyl moiety has a chiral 10 axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

[0107]

[24] The optically active binaphthyl diester compound according to [23] above, wherein R^1 , R^3 , R^5 , and R^6 in the 15 formula (3a) are each independently a hydrogen atom; and R^2 and R^4 are identical to one another and are each represented by the formula (2a).

[0108]

[25] The optically active binaphthyl diester compound 20 according to [23] above, wherein in the formula (5a), R^1 , R^3 , R^5 , and R^6 are each independently a hydrogen atom, R^2 and R^4 are identical to one another and are each represented by the formula (2a), and R^{13} , R^{14} , and R^{15} in the formula (2a) are each independently a substituent selected from the group consisting 25 of a methyl group, an ethyl group, an n-propyl group, an

isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0109]

5 [26] An optically active binaphthyl diester compound represented by the following formula (5b):

[0110]



[0111]

10 [wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 carbon atoms and may or

15 may not be substituted with fluorine, a straight, branched or cyclic heteroalkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or

20 cyclic alkynyl group that has 3 to 18 carbon atoms and may

or may not be substituted with fluorine, an alkoxy group that has 1 to 18 carbon atoms and may or may not be substituted with fluorine, an aryl group that has 5 to 20 carbon atoms and may or may not be substituted with fluorine, an aralkyl group 5 that has 5 to 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine;

[0112]

10 with the proviso that at least one of R^1 , R^2 , R^3 , R^4 , R^5 , and R^6 is a substituent represented by the following formula (2b):

[0113]

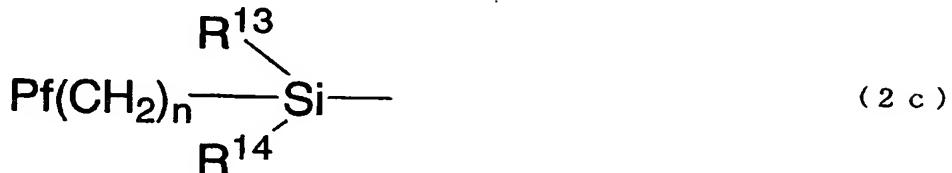


[0114]

15 (wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, 20 branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen

atoms substituted with fluorine atoms, or a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, and n is an integer from 0 to 4.), and/or by the following formula (2c):

5 [0115]



[0116]

(wherein Pf and n are as defined in the formula (2b) above,

[0117]

10 R^{13} and R^{14} are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms,

15 an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms.); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or

20 (S)].

[0118]

[27] The optically active binaphthyl diester compound according to [26] above, wherein R^1 , R^3 , R^5 , and R^6 in the

formula (5b) are each independently a hydrogen atom; and R² and R⁴ are identical to one another and are each represented by the formula (2c).

[0119]

5 [28] The optically active binaphthyl diester compound according to [26] above, wherein in the formula (5b), R¹, R³, R⁵, and R⁶ are each independently a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c); and in the formula (2c), n is 2, R¹³ and R¹⁴ are 10 each a methyl group, and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

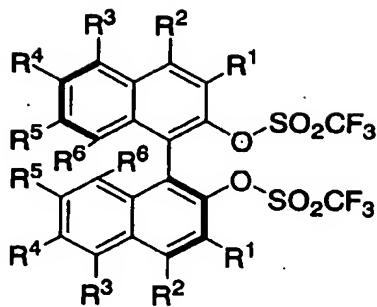
[0120]

15 [29] A method for producing the compound according to any of [16] to [21] above represented by the formula (4a) or (4b), characterized in that the optically active binaphthyl diester compound according to any of [23] to [28] above represented by the formula (5a) or (5b) is reacted with a hydrogen anion.

[0121]

20 [30] An optically active binaphthyl compound represented by the following formula (6a):

[0122]



(6 a)

[0123]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

5 having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

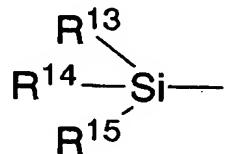
10 having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0124]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

15

[0125]



(2 a)

[0126]

(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group,

an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18
5 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and

[0127]

10 the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

[31] The optically active binaphthyl compound according to

[30] above, wherein R^1 , R^3 , R^5 , and R^6 in the formula (6a) are each independently a hydrogen atom; and R^2 and R^4 are identical
15 to one another and are each represented by the formula (2a).

[0128]

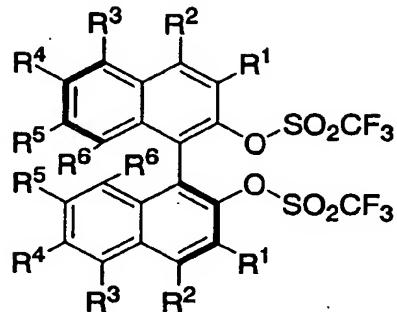
[32] The optically active binaphthyl compound according to

[30] above, wherein in the formula (6a), R^1 , R^3 , R^5 , and R^6 are each independently a hydrogen atom, and R^2 and R^4 are identical
20 to one another and are each represented by the formula (2a); and R^{13} , R^{14} , and R^{15} in the formula (2a) are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a
25 tert-butyl group, an n-octyl group, and a phenyl group.

[0129]

[33] An optically active binaphthyl compound represented by the following formula (6b):

[0130]



(6b)

5

[0131]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or 10 may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic heteroalkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched 15 or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, an alkoxy group that has 1 to 18 carbon atoms and may or may not be substituted 20 with fluorine, an aryl group that has 5 to 20 carbon atoms and

may or may not be substituted with fluorine, an aralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with

5 fluorine;

[0132]

with the proviso that at least one of R^1 , R^2 , R^3 , R^4 , R^5 , and R^6 is a substituent represented by the following formula (2b):

[0133]

$Pf(CH_2)_n$ ————— (2 b)

10

[0134]

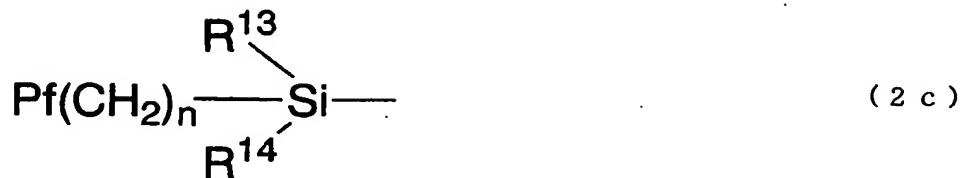
(wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or

15 cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms,

20 an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, and n is an integer

from 0 to 4.), and/or by the following formula (2c):

[0135]



[0136]

5 (wherein Pf and n are as defined in the formula (2b) above,

[0137]

R¹³ and R¹⁴ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or 10 cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon 15 atoms.); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

[0138]

[34] The optically active binaphthyl compound according to 20 [33] above, wherein R¹, R³, R⁵, and R⁶ in the formula (6b) are each independently a hydrogen atom; and R² and R⁴ are identical to one another and are each represented by the formula (2c).

[0139]

[35] The optically active binaphthyl compound according to [33] above, wherein in the formula (6b), R¹, R³, R⁵, and R⁶ are each independently a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c); 5 and in the formula (2c), n is 2, R¹³ and R¹⁴ are each a methyl group, and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

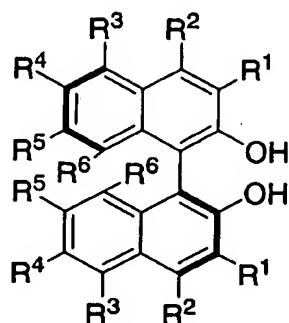
[0140]

[36] A method for producing the optically active binaphthyl 10 diester compound of the formula (5a) or (5b) according to any of [23] to [28], characterized in that the optically active binaphthyl compound of the formula (6a) or (6b) according to any of [30] to [35] is reacted with carbon monoxide and methanol in the presence of a palladium catalyst and an 15 organic base.

[0141]

[37] An optically active binaphthol compound represented by the following formula (7a):

[0142]



(7 a)

[0143]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0144]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

15 [0145]



[0146]

(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an

aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

[0147]

[38] The optically active binaphthol compound according to [37] above, wherein R^1 , R^3 , R^5 , and R^6 in the formula (7a) are each independently a hydrogen atom; and R^2 and R^4 are identical to one another and are each represented by the formula (2a).

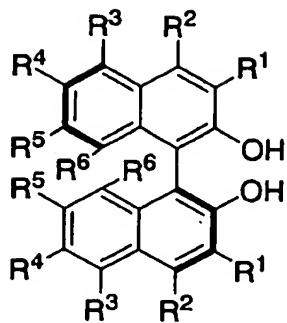
[0148]

[39] The optically active binaphthol compound according to [37] above, wherein in the formula (7a), R^1 , R^3 , R^5 , and R^6 are each independently a hydrogen atom, R^2 and R^4 are identical to one another and are each represented by the formula (2a), and R^{13} , R^{14} , and R^{15} in the formula (2a) are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0149]

[40] An optically active binaphthol compound represented by the following formula (7b):

[0150]



(7 b)

[0151]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic heteroalkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, an alkoxyl group that has 1 to 18 carbon atoms and may or may not be substituted with fluorine, an aryl group that has 5 to 20 carbon atoms and may or may not be substituted with fluorine, an aralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine]

fluorine;

[0152]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2b):

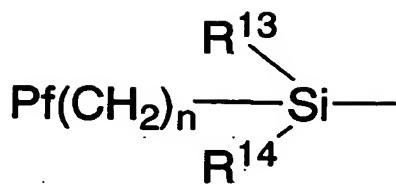
5 [0153]

$\text{Pf}(\text{CH}_2)_n$ ————— (2 b)

[0154]

(wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, and n is an integer from 0 to 4.), and/or by the following formula (2c):

[0155]



(2c)

[0156]

(wherein Pf and n are as defined in the formula (2b) above,

[0157]

5 R¹³ and R¹⁴ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms.); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or

10 (S)].

[0158]

[41] The optically active binaphthol compound according to [40] above, wherein R¹, R³, R⁵, and R⁶ in the formula (7b) are each independently a hydrogen atom; and R² and R⁴ are identical to one another and are each represented by the formula (2c).

[0159]

[42] The optically active binaphthol compound according to

[40] above, wherein in the formula (7b), R¹, R³, R⁵, and R⁶ are each independently a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c); and in the formula (2c), n is 2, R¹³ and R¹⁴ are each a methyl group, and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

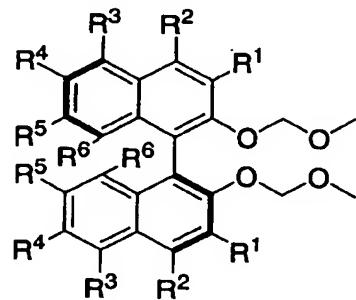
[0160]

[43] A method for producing the optically active binaphthyl compound according to any of [30] to [35] above represented by the formula (6a) or (6b), characterized in that the optically active binaphthol compound according to any of [37] to [42] above represented by the formula (7a) or (7b) is reacted with a triflating agent.

[0161]

[44] An optically active binaphthyl bis-methoxymethyl ether compound represented by the following formula (8a):

[0162]



(8 a)

[0163]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight,

branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0164]

10 with the proviso that at least one of R^1 , R^2 , R^3 , R^4 , R^5 , and R^6 is a substituent represented by the following formula (2a):

[0165]



[0166]

15 (wherein R^{13} , R^{14} , and R^{15} are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and the binaphthyl moiety has a chiral

axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

[0167]

[45] The optically active binaphthyl bis-methoxymethyl ether 5 compound according to [44] above, wherein R¹, R³, R⁵, and R⁶ in the formula (8a) are each independently a hydrogen atom; and R² and R⁴ are identical to one another and are each represented by the formula (2a).

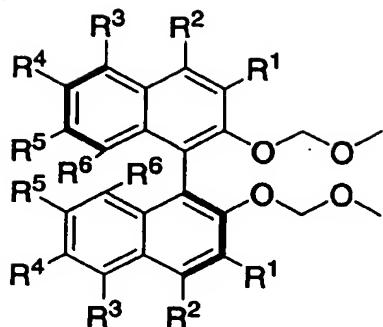
[0168]

10 [46] The optically active binaphthyl bis-methoxymethyl ether compound according to [44] above, wherein in the formula (8a), R¹, R³, R⁵, and R⁶ are each independently a hydrogen atom, R² and R⁴ are identical to one another and are each represented by the formula (2a), and R¹³, R¹⁴, and R¹⁵ in the formula (2a) are 15 each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

20 [0169]

[47] An optically active binaphthyl bis-methoxymethyl ether compound represented by the following formula (8b):

[0170]



(8 b)

[0171]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or may not be substituted with fluorine, a straight, branched or cyclic alkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic heteroalkyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and may or may not be substituted with fluorine, an alkoxy group that has 1 to 18 carbon atoms and may or may not be substituted with fluorine, an aryl group that has 5 to 20 carbon atoms and may or may not be substituted with fluorine, an aralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with fluorine, or a heteroaralkyl group that has 5 to 35 carbon atoms and may or may not be substituted with

fluorine;

[0172]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2b):

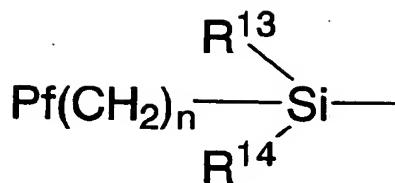
5 [0173]



[0174]

(wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, and n is an integer from 0 to 4.), and/or by the following formula (2c):

[0175]



(2c)

[0176]

(wherein Pf and n are as defined in the formula (2b) above,

[0177]

5 R¹³ and R¹⁴ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms.); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or 10 (S)].

[0178]

[48] The optically active binaphthyl bis-methoxymethyl ether compound according to [47] above, wherein R¹, R³, R⁵, and R⁶ in the formula (8b) are each independently a hydrogen atom; and R² 20 and R⁴ are identical to one another and are each represented by the formula (2c).

[0179]

[49] The optically active binaphthyl bis-methoxymethyl ether compound according to [47] above, wherein in the formula (8b), R¹, R³, R⁵, and R⁶ are each independently a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c); and in the formula (2c), n is 2, R¹³ and R¹⁴ are each a methyl group, and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

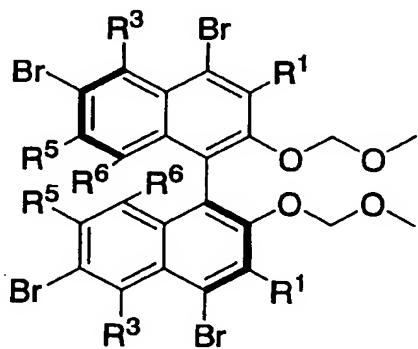
[0180]

[50] A method for producing the optically active binaphthol compound according to any of [37] to [42] above represented by the formula (7a) or (7b), characterized in that the optically active binaphthyl bis-methoxymethyl ether compound according to any of [44] to [49] above represented by the formula (8a) or (8b) is reacted with an acid.

[0181]

[51] An optically active binaphthyl bis-methoxymethyl ether compound represented by the following formula (9a):

[0182]



(9a)

[0183]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or 10 a heteroaralkyl group having 5 to 35 carbon atoms;

[0184]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

[0185]



15

[0186]

(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group 20

having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S)].

5 [0187]

[52] The optically active binaphthyl bis-methoxymethyl ether compound according to [51] above, wherein R¹, R³, R⁵, and R⁶ in the formula (9a) are each independently a hydrogen atom.

[0188]

10 [53] A method for producing the optically active binaphthyl bis-methoxymethyl ether compound according to any of [44] to [46] above represented by the formula (8a), comprising reacting with an alkyl lithium the optically active binaphthyl bis-methoxymethyl ether compound according to any of [51] or 15 [52] above represented by the formula (9a), and subsequently reacting with the reaction product a silyl chloride represented by the following formula (10a):

[0189]



20 [0190]

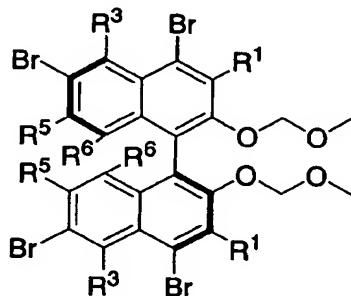
(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched

or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group 5 having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms).

[0191]

[54] A method for producing the optically active binaphthyl bis-methoxymethyl ether compound according to any of claims 47 10 to 49 represented by the formula (8b), comprising reacting with an alkyl lithium an optically active binaphthyl bis-methoxymethyl ether compound represented by the following formula (9b):

[0192]



(9 b)

15

[0193]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a halogen atom, a methyl group that may or may not be substituted with fluorine, an ethyl group that may or 20 may not be substituted with fluorine, a straight, branched or

cyclic alkyl group that has 3 to 18 carbon atoms and may or
may not be substituted with fluorine, a straight, branched or
cyclic heteroalkyl group that has 3 to 18 carbon atoms and may
or may not be substituted with fluorine, a straight, branched
5 or cyclic alkenyl group that has 3 to 18 carbon atoms and may
or may not be substituted with fluorine, a straight, branched
or cyclic alkynyl group that has 3 to 18 carbon atoms and may
or may not be substituted with fluorine, an alkoxy group that
has 1 to 18 carbon atoms and may or may not be substituted
10 with fluorine, an aryl group that has 5 to 20 carbon atoms and
may or may not be substituted with fluorine, an aralkyl group
that has 5 to 35 carbon atoms and may or may not be
substituted with fluorine, or a heteroaralkyl group that has 5
to 35 carbon atoms and may or may not be substituted with
15 fluorine;

[0194]

with the proviso that at least one of R^1 , R^2 , R^3 , R^4 , R^5 , and R^6
is a substituent represented by the following formula (2b):

[0195]

$Pf(CH_2)_n$ —

(2b)

20

[0196]

(wherein Pf is a straight, branched or cyclic alkyl group that
has 2 to 18 carbon atoms and has all the hydrogen atoms

substituted with fluorine atoms, a straight, branched or
cyclic alkenyl group that has 3 to 18 carbon atoms and has all
the hydrogen atoms substituted with fluorine atoms, a straight,
branched or cyclic alkynyl group that has 3 to 18 carbon atoms
5 and has all the hydrogen atoms substituted with fluorine atoms,
an aryl group that has 5 to 20 carbon atoms and has all the
hydrogen atoms substituted with fluorine atoms, an aralkyl
group that has 5 to 25 carbon atoms and has all the hydrogen
atoms substituted with fluorine atoms, or a heteroaralkyl
10 group that has 5 to 25 carbon atoms and has all the hydrogen
atoms substituted with fluorine atoms, and n is an integer
from 0 to 4.), and/or by the following formula (2c):

[0197]



15 [0198]

(wherein Pf and n are as defined in the formula (2b) above,

[0199]

R¹³ and R¹⁴ are each independently a methyl group, an ethyl
group, a vinyl group, a straight, branched or cyclic alkyl
20 group having 3 to 18 carbon atoms, a straight, branched or
cyclic alkenyl group having 3 to 18 carbon atoms, a straight,
branched or cyclic alkynyl group having 3 to 18 carbon atoms,

an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, a heteroaralkyl group having 5 to 25 carbon atoms, or a substituent represented by the formula (2b)); and

5 [0200]

the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S).], and subsequently reacting with the reaction product a compound represented by the following formula (10c):

10 [0201]



[0202]

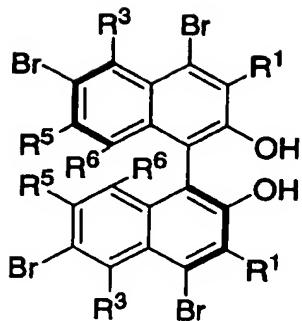
[wherein Pf is a straight, branched or cyclic alkyl group that has 2 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkenyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a straight, branched or cyclic alkynyl group that has 3 to 18 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aryl group that has 5 to 20 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkenyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, an aralkynyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkenyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a heteroaralkynyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, or a substituent represented by the formula (2b)); and

atoms substituted with fluorine atoms, a heteroaralkyl group that has 5 to 25 carbon atoms and has all the hydrogen atoms substituted with fluorine atoms, n is an integer from 0 to 4, and R¹³ and R¹⁴ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, a heteroaralkyl group having 5 to 25 carbon atoms, or a substituent represented by the formula (2b).]

[0203]

[55] A method for producing the optically active binaphthyl bis-methoxymethyl ether compound according to any of [51] or [52] above represented by the formula (9a), comprising forming a binaphthoxide from an optically active binaphthol compound represented by the following formula (11a) in the presence of an acid-capturing agent or by treatment with a base:

20 [0204]



(11a)

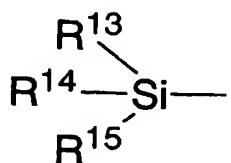
[0205]

[wherein R¹, R², R³, R⁴, R⁵, and R⁶ are each independently a hydrogen atom, a methyl group, an ethyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic heteroalkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 35 carbon atoms, or a heteroaralkyl group having 5 to 35 carbon atoms;

[0206]

with the proviso that at least one of R¹, R², R³, R⁴, R⁵, and R⁶ is a substituent represented by the following formula (2a):

[0207]



(2a)

[0208]

(wherein R¹³, R¹⁴, and R¹⁵ are each independently a methyl group, an ethyl group, a vinyl group, a straight, branched or cyclic alkyl group having 3 to 18 carbon atoms, a straight, branched or cyclic 5 alkenyl group having 3 to 18 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 18 carbon atoms, an alkoxy group having 1 to 18 carbon atoms, an aryl group having 5 to 20 carbon atoms, an aralkyl group having 5 to 25 carbon atoms, or a heteroaralkyl group having 5 to 25 carbon atoms); and

[0209]

the binaphthyl moiety has a chiral axis so that the absolute configuration of the binaphthyl moiety is (R) or (S).], and subsequently reacting the binaphthoxide with chloromethyl 15 ether.

[0210]

[56] A method for stereoselectively producing a compound represented by the following formula (14):

[0219]



20

[0220]

[wherein R¹⁶, R¹⁷, R¹⁸, R¹⁹, and A are as defined above, and the

chiral carbon indicated by an asterisk '*' has an absolute configuration of (R) or (S)], comprising reacting, in a two-phase solution, a Schiff base of a glycine ester or an amide represented by the following formula (12):

5 [0211]



[0212]

[wherein R^{16} and R^{17} are each independently a hydrogen atom or an aryl group that has 5 to 10 carbon atoms and may or may not 10 be substituted with halogen,

[0213]

with the proviso that R^{16} and R^{17} are not a hydrogen atom at the same time;

[0214]

15 R^{18} is a straight, branched or cyclic alkyl group having 1 to 6 carbon atoms; and

[0215]

A is an oxygen atom or a nitrogen atom having a single hydrogen atom bound thereto] with an alkyl halide represented 20 by the following formula (13):

[0216]

R¹⁹—Y

(13)

[0217]

[wherein R¹⁹ is a straight, branched or cyclic alkyl group having 1 to 10 carbon atoms, a straight, branched or cyclic 5 alkenyl group having 3 to 10 carbon atoms, a straight, branched or cyclic alkynyl group having 3 to 10 carbon atoms, or an aralkyl group that has 5 to 25 carbon atoms and may or may not have its nucleus substituted with 1 to 15 halogen atoms; and

10 [0218]

Y is a chlorine atom, a bromine atom, or an iodine atom] in the presence of an optically active quaternary ammonium salt according to [1] to [8] above represented by the formula (1a) or (1b) and an inorganic base.

15 [0221]

[57] The method according to [56] above, wherein the reaction is carried out in a three-phase solution comprising an organic solvent with hydrogen atoms substituted with fluorine atoms, an organic solvent, and water.

20 [0222]

[58] A method for recovering an optically active quaternary ammonium salt, characterized in that an organic solvent, water, a mixed solvent of an organic solvent and water, and/or an

organic solvent with hydrogen atoms substituted with fluorine atoms are/is used to separate the optically active quaternary ammonium salt according to any of claims 5 to 8 represented by the formula (1b) from a product containing the ammonium salt.

5 [0223]

[59] A method for recovering the optically active quaternary ammonium salt according to any of [5] to [8] above represented by the formula (1b), characterized in that, following the production of the compound of the formula (14) by the method 10 according to [56] above, which is carried out in the presence of the optically active quaternary ammonium salt of the formula (1b), the ammonium salt is separated from the reaction mixture containing the optically active quaternary ammonium salt by using an organic solvent, water, a mixed solvent of an 15 organic solvent and water, and/or an organic solvent with hydrogen atoms substituted with fluorine atoms.

[0224]

[60] The method according to [59] above, wherein hexane with its hydrogen atoms substituted with fluorine atoms is used as 20 the fluorine-substituted organic solvent.

ADVANTAGE OF THE INVENTION

[0225]

The axially chiral, optically active spiro-quaternary ammonium salts of the formula (1a) provided in accordance with 25 the present invention can give a high stereoselectivity of 90%

ee or above when used as a phase-transfer catalyst in the asymmetric alkylation of a glycine derivative, and can be applied to a broader range of substrates with high selectivity. The ammonium salts are advantageous since fewer steps are 5 involved in the synthesis of the catalysts. Furthermore, when used as a phase-transfer catalyst, the ammonium salts allow the stereoselective production of optically active α -amino acid derivatives, useful intermediates in the synthesis of pharmaceutical or agrochemical products. Because of these 10 advantages, the present invention is of significant importance in industrial applications.

[0226]

The fluorine-containing optically active quaternary ammonium salts of the formula (1b) provided in accordance with 15 the present invention are spiro compounds with a chiral axis and can serve as effective phase-transfer catalysts when used in the asymmetric alkylation of glycine derivatives. Furthermore, the optically active quaternary ammonium salts can be readily produced, recovered, and purified, and can 20 retain high catalytic activity after they are recycled. Furthermore, when used as a phase-transfer catalyst, the optically active quaternary ammonium salts allow the stereoselective production of optically active α -amino acid derivatives, useful intermediates in the synthesis of 25 pharmaceutical or agrochemical products. These advantages.

further add to the industrial importance of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0227]

5 The present invention will now be described in detail.

[0228]

While the optically active quaternary ammonium salt of the present invention shown by the formula (1a) may be any of the compounds defined above, it preferably is a compound in which R¹ and R⁷, R³ and R⁹, R⁴ and R¹⁰, R⁵ and R¹¹, and R⁶ and R¹² are in each case identical to one another, R² and R⁸ are identical to one another and are each represented by the formula (2a), and X⁻ is a fluoride ion, a chloride ion, a bromide ion, an iodide ion, a p-toluenesulfonic acid ion, or a hydroxide ion. Of such compounds, particularly preferred are those in which R¹, R³, R⁵, R⁶, R⁷, R⁹, R¹¹, and R¹² are each a hydrogen atom, R², R⁴, R⁸, and R¹⁰ are identical to one another and are each represented by the formula (2a), and X⁻ is a chloride ion, a bromide ion, an iodide ion, or a p-toluenesulfonic acid ion. Of these, even more preferred are those in which X⁻ in the formula (1a) is a bromide ion, and R¹³, R¹⁴, and R¹⁵ in the formula (2a) are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a

tert-butyl group, an n-octyl group, and a phenyl group.

[0229]

Examples of the compound shown by the formula (1a) include, but are not limited to, spiro-bis[{{(R)-1,1'-bi-{4,6-5 bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(propylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(propylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(isopropylsilyl)naphthyl}}-10 2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(tributylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(triphenylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)naphthyl}}-2,2'-dimethyl]ammonium 15 bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(tert-butylidimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(tert-butylidiphenylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium iodide, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium chloride, spiro-bis[{{(R)-1,1'-bi-{4,6-bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium fluoride and spiro-bis[{{(R)-1,1'-bi-

{4,6-bis(trimethylsilyl)naphthyl})-2,2'-dimethyl]ammonium

hydroxide, and the corresponding (S)-forms as enantiomers.

[0230]

While the optically active quaternary ammonium salt of
5 the present invention shown by the formula (1b) may be any of
the compounds defined above, it preferably is a compound in
which R¹ and R⁷, R³ and R⁹, R⁴ and R¹⁰, R⁵ and R¹¹, and R⁶ and R¹²
are in each case identical to one another, R² and R⁸ are
identical to one another and are each represented by the
10 formula (2c), and X⁻ is a fluoride ion, a chloride ion, a
bromide ion, an iodide ion, a p-toluenesulfonic acid ion, or a
hydroxide ion. Of such compounds, more preferred are those in
which R¹, R³, R⁵, R⁶, R⁷, R⁹, R¹¹, and R¹² in the formula (1b) are
each a hydrogen atom, R², R⁴, R⁸, and R¹⁰ are identical to one
15 another and are each represented by the formula (2c), and X⁻ is
a chloride ion, a bromide ion, an iodide ion, or a p-
toluenesulfonic acid ion. Of these, most preferred are those
in which X⁻ in the formula (1b) is a bromide ion, and in the
formula (2c), n is 2, R¹³ and R¹⁴ are each a methyl group, and
20 Pf is an n-octyl group having all the hydrogen atoms
substituted with fluorine atoms.

[0231]

Examples of the compound shown by the formula (1b)
include, but are not limited to, spiro-bis{(R)-1,1'-bi-[4-(2-
25 perfluorooctylethyl)dimethylsilyl]naphthyl-2,2'-

dimethyl}ammonium bromide, spiro-bis{(R)-1,1'-bi-[6-(2-
perfluorooctylethyl)dimethylsilyl]naphthyl-2,2'-
dimethyl}ammonium bromide, spiro-bis{(R)-1,1'-bi-[4-(2-
perfluorooctylethyl)dimethylsilyl-6-(2-
5 perfluorooctyl)ethyl]naphthyl-2,2'-dimethyl}ammonium bromide,
spiro-bis{(R)-1,1'-bi-[4,6-bis((2-
perfluorooctylethyl)dimethylsilyl)]naphthyl-2,2'-
dimethyl}ammonium bromide, spiro-bis{(R)-1,1'-bi-[4,6-bis(-
tris(2-perfluorooctylethyl)silyl)]naphthyl-2,2'-
10 dimethyl}ammonium fluoride, spiro-bis{(R)-1,1'-bi-[4,6-bis((2-
perfluorooctylethyl)dimethylsilyl)]naphthyl-2,2'-
dimethyl}ammonium chloride, spiro-bis{(R)-1,1'-bi-[4,6-bis((2-
perfluorooctylethyl)dimethylsilyl)]naphthyl-2,2'-
15 dimethyl}ammonium iodide, spiro-bis{(R)-1,1'-bi-[4,6-bis((2-
perfluorooctylethyl)dimethylsilyl)]naphthyl-2,2'-
dimethyl}ammonium hydroxide, and spiro-bis{(R)-1,1'-bi-[4,6-
bis((2-perfluorooctylethyl)dimethylsilyl)]naphthyl-2,2'-
20 dimethyl}ammonium-4-methylbenzene sulfonate, and the
corresponding (S)-forms as enantiomers.

[0232]

While the optically active binaphthyl compound of the
present invention shown by the formula (3a) may be any of the
25 compounds defined above, it preferably is a compound in which

R^1 , R^3 , R^5 , and R^6 are each a hydrogen atom, and R^2 and R^4 are identical to one another and are each represented by the formula (2a). Of these, particularly preferred are those in which R^{13} , R^{14} , and R^{15} in the formula (2a) are each 5 independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group. Of these compounds, those in which X is a 10 chlorine atom, a bromine atom, an iodine atom, or p-toluenesulfonyloxy group are preferred, with ones in which X is a bromine atom being particularly preferred.

[0233]

Examples of the optically active binaphthyl compound of 15 the present invention shown by the formula (3a) include, but are not limited to, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(trimethylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(triethylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(propylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(triisopropylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(tributylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(triphenylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(dimethyloctylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(tert-butyldimethylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis(dimethylphenylsilyl)}naphthyl,

(R)-1,1'-bi-{2-bromomethyl-4,6-bis(tert-
butyldiphenylsilyl)}naphthyl, (R)-1,1'-bi-{2-chloromethyl-4,6-
bis(trimethylsilyl)}naphthyl, (R)-1,1'-bi-{2-chloromethyl-4,6-
bis(trimethylsilyl)}naphthyl and (R)-1,1'-bi-{2-iodomethyl-
5 4,6-bis(trimethylsilyl)}naphthyl, and the corresponding (S)-
forms as enantiomers.

[0234]

The optically active binaphthyl compound of the present invention shown by the formula (3b) is preferably such that R¹,
10 R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c). Of such compounds, particularly preferred are those in which X in the formula (3b) is a bromine atom, and in the formula (2c), n is 2, R¹³ and R¹⁴ are each a methyl group,
15 and Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms.

[0235]

Examples of the optically active binaphthyl compound of the present invention shown by the formula (3b) include, but
20 are not limited to, (R)-1,1'-bi-{2-bromomethyl-4-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-bromomethyl-6-(2-perfluoroctylethyl)dimethylsilyl}naphthyl,
perfluoroctylethyl)dimethylsilyl-6-(2-
(R)-1,1'-bi-{2-bromomethyl-4-(2-
perfluoroctylethyl)dimethylsilyl-6-(2-
25 perfluoroctyl)ethyl}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-

bis((2-perfluorooctylethyl)dimethylsilyl)}naphthyl, (R)-1,1'-bi-{2-bromomethyl-4,6-bis[-tris(2-perfluorooctylethyl)silyl]}naphthyl, (R)-1,1'-bi-{2-chloromethyl-4,6-bis[(2-perfluorooctylethyl)dimethylsilyl]}naphthyl, (R)-1,1'-bi-{2-iodomethyl-4,6-bis((2-perfluorooctylethyl)dimethylsilyl)}naphthyl and (R)-1,1'-bi-{2-(4-methylbenzenesulfonyloxy)methyl-4,6-bis[(2-perfluorooctylethyl)dimethylsilyl]}naphthyl, and the 10 corresponding (S)-forms as enantiomers.

[0236]

The compound of the present invention represented by the formula (1a) or (1b) can be obtained by reacting the optically active binaphthyl compound of the formula (3a) or (3b) with 15 ammonia. The ammonia used may be a 10wt% to saturated aqueous ammonia and preferably a 20 to 28wt% aqueous ammonia. Water or an organic solvent inert to the reaction may be added as a solvent. The reaction is preferably carried out in a sealed condition to avoid loss of ammonia. The amount of ammonia used 20 is typically 1 to 8 equivalents, and preferably 2 to 5 equivalents, relative to the substrate used. The reaction is typically carried out at a temperature of 5°C to 30°C and at a substrate concentration of 5 to 20wt%, and is carried out over a time period of typically 5 to 72 hours, and preferably 10 to 25 36 hours. In this manner, the desired ammonium salt can be

obtained in high yield.

[0237]

While the optically active binaphthyl dihydroxy compound of the present invention shown by the formula (4a) may be any 5 of the compounds defined above, it preferably is a compound in which R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2a). Of these, particularly preferred are those in which R¹³, R¹⁴, and R¹⁵ in the formula (2a) are each 10 independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

15 [0238]

Examples of the optically active binaphthyl dihydroxy compound of the present invention shown by the formula (4a) include, but are not limited to, (R)-1,1'-bi-{4,6-bis(trimethylsilyl)-2-hydroxymethyl}naphthyl, (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-hydroxymethyl}naphthyl, (R)-1,1'-bi-{4,6-bis(propylsilyl)-2-hydroxymethyl}naphthyl, (R)-1,1'-bi-{4,6-bis(triisopropylsilyl)-2-hydroxymethyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-hydroxymethyl}naphthyl, (R)-1,1'-bi-{4,6-bis(triphenylsilyl)-2-hydroxymethyl}naphthyl, 25 (R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-

hydroxymethyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tert-butyldimethylsilyl)-2-hydroxymethyl)naphthyl, (R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-hydroxymethyl)naphthyl and (R)-1,1'-bi-{4,6-bis(tert-butyldiphenylsilyl)-2-hydroxymethyl}naphthyl, and the corresponding (S)-forms as enantiomers.

5 [0239]

The optically active binaphthyl dihydroxy compound of the present invention shown by the formula (4b) is preferably such that R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c). Of such compounds, most preferred are those in which in the formula (2c), R¹³ and R¹⁴ are each a methyl group, Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms, and n is 2.

15 [0240]

Examples of the optically active binaphthyl dihydroxy compound of the present invention shown by the formula (5) include (R)-1,1'-bi-{2-hydroxymethyl-4-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-hydroxymethyl-6-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-hydroxymethyl-4-(2-perfluoroctylethyl)dimethylsilyl-6-(2-perfluoroctyl)ethyl}naphthyl, (R)-1,1'-bi-{2-hydroxymethyl-4,6-bis[(2-perfluoroctylethyl)dimethylsilyl]}naphthyl and

(R)-1,1'-bi-{2-hydroxymethyl-4,6-bis[-tris(2-perfluorooctylethyl)silyl]}naphthyl, and the corresponding (S)-forms as enantiomers.

[0241]

5 The optically active binaphthyl compound of the present invention represented by the formula (3a) or (3b) can be obtained as follows: For example, when it is desired to produce a halogenated product, the optically active binaphthyl dihydroxy compound of the formula (4a) or (4b) is reacted with 10 triphenylphosphine, and carbon tetrabromide or carbon tetrachloride in a proper solvent such as tetrahydrofuran. The reaction is carried out at a substrate concentration of typically 5 to 20wt% and at a temperature of typically -10°C to 50°C, and preferably 10°C to 30°C, and is carried out over 15 a time period of typically 10 minutes to 10 hours, and preferably 1 hour to 5 hours. In this manner, the desired dihalogenated product can be obtained in high yield. When it is desired to produce a sulfonyloxy product, the optically active binaphthyl dihydroxy compound (4a) or (4b) is reacted 20 with p-toluenesulfonyl chloride in a proper solvent such as dichloromethane and in the presence of an acid-capturing agent such as triethylamine. The reaction is carried out at a substrate concentration of typically 5 to 20wt% and at a temperature of typically -40°C to 20°C, and preferably -10°C to 10°C, and is carried out over a time period of typically 10

minutes to 10 hours, and preferably 1 hour to 5 hours. In this manner, the desired sulfonyloxy product can be obtained in high yield.

[0242]

5 While the optically active binaphthyl diester compound of the present invention shown by the formula (5a) may be any of the compounds defined above, it preferably is a compound in which R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the 10 formula (2a). Of these, particularly preferred are those in which R¹³, R¹⁴, and R¹⁵ in the formula (2a) are each independently a substituent selected from the group consisting 15 of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0243]

Examples of the optically active binaphthyl diester compound of the present invention shown by the formula (5a) 20 include (R)-1,1'-bi-{4,6-bis(trimethylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(propylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(triisopropylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-methoxycarbonyl}naphthyl,

(R)-1,1'-bi-{4,6-bis(triphenylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tert-butyldimethylsilyl)-2-methoxycarbonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-methoxycarbonyl}naphthyl and (R)-1,1'-bi-{4,6-bis(tert-butyldiphenylsilyl)-2-methoxycarbonyl}naphthyl, and the corresponding (S)-forms as enantiomers.

10 [0244]

The optically active binaphthyl diester compound of the present invention shown by the formula (5b) is preferably such that R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c). Of such compounds, particularly preferred are those in which in the formula (2c), R¹³ and R¹⁴ are each a methyl group, Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms, and n is 2.

[0245]

20 Examples of the optically active binaphthyl diester compound of the present invention shown by the formula (5b) include, but are not limited to, (R)-1,1'-bi-{2-methoxycarbonyl-4-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-methoxycarbonyl-6-(2-

perfluorooctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-methoxycarbonyl-4-(2-perfluorooctylethyl)dimethylsilyl-6-(2-perfluorooctyl)ethyl}naphthyl, (R)-1,1'-bi-{2-methoxycarbonyl-4,6-bis[(2-perfluorooctylethyl)dimethylsilyl]}naphthyl and 5 (R)-1,1'-bi-{2-methoxycarbonyl-4,6-bis[-tris(2-perfluorooctylethyl)silyl]}naphthyl, and the corresponding (S)-forms as enantiomers.

[0246]

The optically active binaphthyl dihydroxy compound of the 10 present invention represented by the formula (4a) or (4b) can be obtained, for example, by reacting the optically active binaphthyl diester compound of the formula (5a) or (5b) with a hydrogen anion such as LiAlH₄ in a proper solvent such as tetrahydrofuran. The reaction is carried out at a substrate 15 concentration of typically 5 to 30wt% and at a temperature of typically -20°C to 30°C, and preferably -10°C to 10°C, and is carried out over a time period of typically 10 minutes to 5 hours, and preferably 20 minutes to 2 hours. In this manner, 20 the desired dihydroxyl methyl product can be obtained in high yield.

[0247]

While the optically active binaphthyl compound of the present invention shown by the formula (6a) may be any of the compounds defined above, it preferably is a compound in which 25 R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are

identical to one another and are each represented by the formula (2a). Of these, particularly preferred are those in which R¹³, R¹⁴, and R¹⁵ in the formula (2a) are each independently a substituent, selected from the group consisting 5 of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0248]

10 Examples of the optically active binaphthyl compound of the present invention shown by the formula (6a) include, but are not limited to, (R)-1,1'-bi-{4,6-bis(trimethylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tripropylsilyl)-2-trifluoromethanesulfonyl}naphthyl, 15 (R)-1,1'-bi-{4,6-bis(triisopropylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tri phenylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-20 1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(tert-butyldimethylsilyl)-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-trifluoromethanesulfonyl}naphthyl and (R)-1,1'-bi-{4,6-25 trifluoromethanesulfonyl}naphthyl and (R)-1,1'-bi-{4,6-

bis(tert-butyldiphenylsilyl)-2-

trifluoromethanesulfonyl}naphthyl, and the corresponding enantiomers, or (S)-forms.

[0249]

5 The optically active binaphthyl compound of the present invention shown by the formula (6b) is preferably such that R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c). Of such compounds, particularly preferred are 10 those in which in the formula (2c), R¹³ and R¹⁴ are each a methyl group, Pf is an n-octyl group having all the hydrogen atoms substituted with fluorine atoms, and n is 2.

[0250]

Examples of the optically active binaphthyl compound of 15 the present invention shown by the formula (6b) include (R)-1,1'-bi-{4-(2-perfluorooctylethyl)dimethylsilyl-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{6-(2-perfluorooctylethyl)dimethylsilyl-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4-(2-perfluorooctylethyl)dimethylsilyl-6-(2-perfluorooctyl)ethyl-2-trifluoromethanesulfonyl}naphthyl, (R)-1,1'-bi-{4,6-bis[(2-perfluorooctylethyl)dimethylsilyl]-2-trifluoromethanesulfonyl}naphthyl and (R)-1,1'-bi-{4,6-bis[-tris(2-perfluorooctylethyl)silyl]-2-trifluoromethanesulfonyl}naphthyl, and the corresponding (S)-

forms as enantiomers.

[0251]

The optically active binaphthyl dimethyl ester compound of the present invention represented by the formula (5a) or 5 (5b) can be obtained, for example, by reacting the optically active binaphthyl compound of the formula (6a) or (6b) with carbon monoxide and methanol in a proper solvent such as dimethyl sulfoxide in the presence of a palladium catalyst and an organic base, such as diisopropylethylamine, for capturing 10 an acid, in a carbon monoxide atmosphere, which may be pressurized. The reaction is carried out at a substrate concentration of typically 5 to 30wt% under a pressure of typically 1 to 30atm, and preferably 5 to 20atm, and at a temperature of typically room temperature to 200°C, and 15 preferably 80°C to 130°C, and is typically carried out over a time period of 24 to 72 hours. The palladium catalyst may have no valency or it may be prepared in the reaction system from a divalent acetate or the like. The palladium catalyst is typically used in an amount of 5 to 20mol% relative to the 20 substrate. The base is used in an amount of typically 2 to 8 equivalents, and preferably 2.5 to 5 equivalents, relative to the substrate. Methanol is used in an amount of 2 to 200 equivalents, and preferably 10 to 50 equivalents, relative to the substrate. In this manner, the desired diester product can 25 be obtained in high yield.

[0252]

While the optically active binaphthol compound of the present invention shown by the formula (7a) may be any of the compounds defined above, it preferably is a compound in which 5 R^1 , R^3 , R^5 , and R^6 are each a hydrogen atom, and R^2 and R^4 are identical to one another and are each represented by the formula (2a). Of these, most preferred are those in which R^{13} , R^{14} , and R^{15} in the formula (2a) are each independently a 10 substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a phenyl group.

[0253]

Examples of the optically active binaphthol compound of 15 the present invention shown by the formula (7a) include, but are not limited to, (R)-1,1'-bi-{4,6-bis(trimethylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(propylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(triisopropylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(triphenylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(tert-butylidimethylsilyl)-2-hydroxy}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-hydroxy}naphthyl and (R)-1,1'-bi-

{4,6-bis(tert-butyldiphenylsilyl)-2-hydroxy}naphthyl, and the corresponding (S)-forms as enantiomers.

[0254]

The optically active binaphthol compound of the present invention shown by the formula (7b) is preferably such that R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c). Of such compounds, particularly preferred are those in which R¹³ and R¹⁴ are each a methyl group, Pf is an n-octyl group with all the hydrogen atoms substituted with fluorine atoms, and n is 2 in the formula (2c).

[0255]

Specific examples of the optically active binaphthol compound of the present invention shown by the formula (7b) include (R)-1,1'-bi-{2-hydroxy-4-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-hydroxy-6-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-hydroxy-4-(2-perfluoroctylethyl)dimethylsilyl-6-(2-perfluoroctyl)ethyl}naphthyl, (R)-1,1'-bi-{2-hydroxy-4,6-bis[(2-perfluoroctylethyl)dimethylsilyl]}naphthyl and (R)-1,1'-bi-{2-hydroxy-4,6-bis[-tris(2-perfluoroctylethyl)silyl]}naphthyl, and the corresponding (S)-forms as enantiomers.

[0256]

The optically active binaphthyl compound of the present

invention represented by the formula (6a) or (6b) can be obtained, for example, by reacting the optically active binaphthol compound of the formula (7a) or (7b) with a triflating agent, such as a trifluoromethanesulfonic acid 5 anhydride or trifluoromethanesulfonyl chloride, in an inert solvent such as dichloromethane in the presence of an organic base such as triethylamine. The reaction is typically carried out at a substrate concentration of 5 to 30wt% and at a temperature of -78°C to room temperature, and is typically 10 carried out over a time period of 30 minutes to 3 hours. In this manner, the desired ditriflate product can be obtained in high yield.

[0257]

While the optically active binaphthyl bis-methoxymethyl ether compound of the present invention shown by the formula 15 (8a) may be any of the compounds defined above, it preferably is a compound in which R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2a). Of these, most preferred are 20 those in which R¹³, R¹⁴, and R¹⁵ in the formula (2a) are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, an n-octyl group, and a 25 phenyl group.

[0258]

Examples of the optically active binaphthyl diether compound of the present invention shown by the formula (8a) include, but are not limited to, (R)-1,1'-bi-{4,6-5 bis(trimethylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(propylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(triisopropylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-methoxymethoxy}naphthyl, 10 (R)-1,1'-bi-{4,6-bis(triphenylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(tert-butyldimethylsilyl)-2-methoxymethoxy}naphthyl, (R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-methoxymethoxy}naphthyl and 15 (R)-1,1'-bi-{4,6-bis(tert-butyldiphenylsilyl)-2-methoxymethoxy}naphthyl, and the corresponding (S)-forms as enantiomers.

[0259]

The optically active binaphthyl bis-methoxymethyl ether compound of the present invention shown by the formula (8b) is 20 preferably such that R¹, R³, R⁵, and R⁶ are each a hydrogen atom, and R² and R⁴ are identical to one another and are each represented by the formula (2c). Of such compounds, particularly preferred are those in which in the formula (2c), 25 R¹³ and R¹⁴ are each a methyl group, Pf is an n-octyl group

having all the hydrogen atoms substituted with fluorine atoms, and n is 2.

[0260]

Examples of the optically active binaphthyl bis-methoxymethyl ether compound of the present invention shown by the formula (8b) include, but are not limited to, (R)-1,1'-bi-{2-methoxymethoxy-4-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-methoxymethoxy-6-(2-perfluoroctylethyl)dimethylsilyl}naphthyl, (R)-1,1'-bi-{2-methoxymethoxy-4-(2-perfluoroctylethyl)dimethylsilyl-6-(2-perfluoroctyl)ethyl}naphthyl, (R)-1,1'-bi-{2-methoxymethoxy-4,6-bis[(2-perfluoroctylethyl)dimethylsilyl]}naphthyl and (R)-1,1'-bi-{2-methoxymethoxy-4,6-bis[-tris(2-perfluoroctylethyl)silyl]}naphthyl, and the corresponding (S)-forms as enantiomers.

[0261]

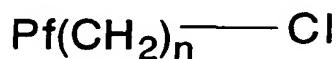
The optically active binaphthol compound of the present invention represented by the formula (7a) or (7b) can be obtained, for example, by reacting the optically active binaphthyl bis-methoxymethyl ether compound of the formula (8a) or (8b) with an organic acid, such as p-toluenesulfonic acid, in a proper solvent, such as dichloromethane and methanol, or a mixed solvent. Preferably, the organic acid is used in an amount of 2 to 3 equivalents relative to the

substrate. The reaction is carried out at a substrate concentration of typically 5 to 20wt% and at a temperature of typically 10°C to 80°C, preferably 30°C to 60°C, and is carried out over a time period of typically 20 minutes to 48 hours, and preferably 2 hours to 24 hours. In this manner, the desired binaphthol product can be obtained in high yield.

[0262]

The optically active binaphthyl bis-methoxymethyl ether compound of the present invention represented by the formula 10 (8a) can be obtained, for example, as follows: The optically active binaphthyl dieter compound of the formula (9a) is reacted with butyl lithium in a proper solvent, such as tetrahydrofuran, to replace the bromine atoms with lithium atoms. The reaction product is then reacted with the silyl 15 chloride of the formula (10a) above, a compound represented by the following formula (10b):

[0263]



(10b)

[0264]

20 (wherein Pf and n are as defined in the formula (2b) above), or the silyl chloride of the formula (10c) above. Using the alkyl lithium in an amount of typically 8 to 12 equivalents relative to the substrate, the reaction is carried out at a substrate concentration of typically 5 to 20wt% and at a

temperature of typically -100°C to -50°C, and preferably -85°C to -75°C, and is carried out over a time period of typically 20 minutes to 3 hours, and preferably 30 minutes to 2 hours. In this manner, the desired lithio product can be obtained. To 5 this product, the alkyl silyl chloride is added, at the same temperature, in an amount of 4 to 8 equivalents relative to the substrate, and the reaction is carried out at a temperature of typically -80°C to 30°C, and preferably 0°C to room temperature, over a time period of typically 20 minutes 10 to 2 hours, and preferably 30 minutes to 1 hour. In this manner, the desired product can be obtained in high yield.

[0265]

While the optically active binaphthyl bis-methoxymethyl ether compound of the present invention shown by the formula 15 (9a) or (9b) may be any of the compounds defined above, it preferably is a compound in which R¹, R³, R⁵ and R⁶ are each a hydrogen atom.

[0266]

While the silyl chloride of the present invention shown 20 by the formula (10a) may be any of the compounds defined above, compounds are particularly preferred in which R¹³, R¹⁴, and R¹⁵ are each independently a substituent selected from the group consisting of a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, 25 a sec-butyl group, a tert-butyl group, an n-octyl group, and a

phenyl group.

[0267]

While the silyl chloride of the present invention shown by the formula (10c) may be any of the compounds defined above, 5 compounds are particularly preferred in which R¹³ and R¹⁴ are each a methyl group, Pf is an n-octyl group with all the hydrogen atoms substituted with fluorine atoms, and n is 2 in the formula (2c).

[0268]

10 The compound of the present invention represented by the formula (9a) can be obtained, for example, by reacting the compound of the formula (11a) with sodium hydride in a solvent, such as tetrahydrofuran, to form an alkoxide, followed by addition of chloromethylmethyl ether. The reaction is carried 15 out at a substrate concentration of typically 5 to 20wt% and at a temperature of typically -40°C to room temperature, and preferably -10°C to 0°C, and is carried out over a time period of typically 20 minutes to 3 hours, and preferably 30 minutes to 2 hours. In this manner, the desired product can be 20 obtained in high yield. Of the compounds shown by the formula (9a), those in which R¹, R³, R⁵, and R⁶ are each a hydrogen atom can be synthesized according to the process described in *J. Org. Chem.*, 2001, 66, 2358.

[0269]

25 The compound of the present invention represented by the

formula (9b) can be obtained by reacting a corresponding binaphthol product with sodium hydride in a solvent, such as tetrahydrofuran, to form an alkoxide, followed by addition of chloromethylmethyl ether. The reaction is carried out at a 5 substrate concentration of typically 5 to 20wt% and at a temperature of typically -40°C to room temperature, and preferably -10°C to 0°C, and is carried out over a time period of typically 20 minutes to 3 hours, and preferably 30 minutes to 2 hours. In this manner, the desired product can be 10 obtained in high yield.

[0270]

According to the present invention, the optically active quaternary ammonium salt of the formula (1a) or (1b) is used as a chiral phase-transfer catalyst.

15 [0271]

In the stereoselective production of the compound of the formula (14), a Schiff base of a glycine ester shown by the formula (12) is asymmetrically alkylated with a halogenated alkyl of the formula (13) in a two-phase solvent system using 20 the optically active quaternary ammonium salt of the formula (1a) or (1b) as a phase-transfer catalyst. The solvent used is a mixture of a water-immiscible hydrocarbon solvent, such as toluene, and a 40 to 60wt% aqueous solution of an alkaline metal, such as potassium hydroxide and cesium hydroxide, with 25 the ratio of the organic phase to the aqueous phase being in

the range of 5:1 to 1:3, preferably, 5:1 to 1:1. This reaction is carried out at a substrate concentration of typically 5 to 20wt% and at a temperature of typically -40°C to 10°C, and preferably -25°C to 5°C, and is carried out over a time period 5 of typically 1 hour to 200 hours, and preferably 5 hours to 180 hours. The amount of the phase-transfer catalyst used is in the range of 0.2 to 2mol%, and preferably in the range of 0.8 to 1.2mol% relative to the substrate. In this manner, the desired optically active α -amino acid derivative can be 10 obtained in high yield in a highly stereoselective manner.

[0272]

In the above-described process, the reaction product shown by the formula (16) is given as an (S)-form when the axially chiral, optically active quaternary ammonium salt of the 15 formula (1a) or (1b) to serve as the phase-transfer catalyst has an absolute configuration of (R, R). Conversely, the product is given as an (R)-form when the catalyst has an absolute configuration of (S, S).

[0273]

20 According to the present invention, the above-described process may be carried out in a three-phase solvent system comprising an organic solvent with the hydrogen atoms substituted with fluorine atoms, an organic solvent and water. The organic solvent with the hydrogen atoms substituted with 25 fluorine atoms may be a fluorous solvent. Examples of fluorous

solvent are perfluorinated alkanes and cycloalkanes, such as perfluorohexane and perfluoromethylcyclohexane. The fluorous solvent is added in an amount of 0.1 to 1.0 times by volume of the organic solvent used.

5 [0274]

According to the present invention, the optically active quaternary ammonium salt of the formula (1b) can be recovered after it has been used in the reaction as a catalyst.

[0275]

10 The ammonium salt can be recovered by using any proper technique: For example, it can be readily recovered by using an organic solvent, water, a mixed solvent of an organic solvent and water and/or an organic solvent with the hydrogen atoms substituted with fluorine atoms, to separate the 15 optically active quaternary ammonium salt of the formula (1b) from a product (e.g., the reaction mixture of the above-described reaction) containing the ammonium salt. When necessary, the reaction mixture is diluted with water and an organic solvent, such as toluene, and is then subjected to 20 separation with a fluorous solvent, such as perfluorinated alkanes and cycloalkanes, including perfluorohexane and perfluoromethylcyclohexane. In this manner, only the catalyst can be recovered from the fluorous layer in high yield.

[0276]

25 According to the present invention, the recovered

catalyst can be purified by removing the fluorous solvent from the fluorous solution by distillation, and subjecting the residue to a silica gel column chromatography using a relatively high polar organic solvent, such as a mixed solvent 5 of dichloromethane/methanol, as an eluant. The crude recovered product obtained by concentrating the fluorous solvent may be directly used as a catalyst in the subsequent reaction.

Examples

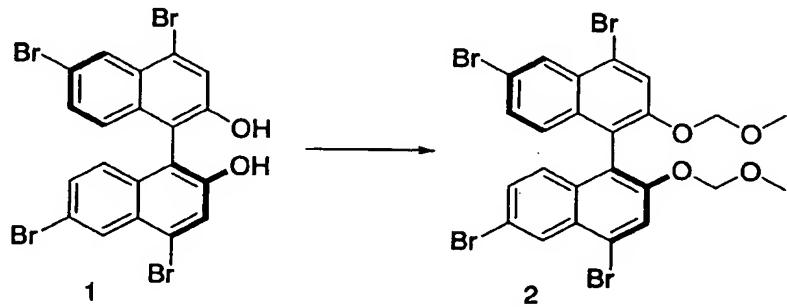
[0277]

10 The present invention will now be described in further detail with reference to examples of axially chiral, optically active spiro-quaternary ammonium salts represented by the formula (1a). These examples, however, are provided by way of example only and are not intended to limit the scope of the 15 invention in any way.

[0278]

Example 1 Synthesis of (R)-1,1'-bi-(4,6-dibromo-2-methoxymethoxy)naphthyl (2)

[0279]



[0280]

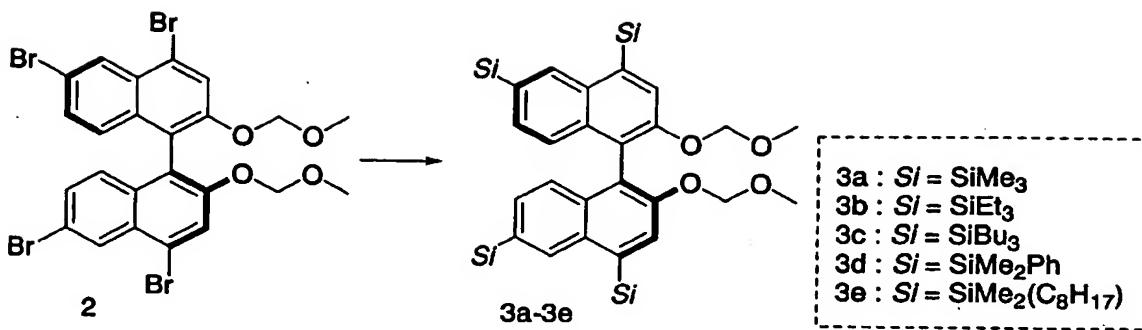
In an argon atmosphere, 60% sodium hydride (0.880 g, 22 mmol) was added to a tetrahydrofuran solution (50 mL) of Compound 1 (6.02 g, 10 mmol) at 0°C and the mixture was stirred for 10 minutes. Subsequently, chloromethyl ether (1.67 mL, 22 mmol) was added at 0°C, and the reaction mixture was allowed to warm to room temperature and was then stirred for 1 hour. After completion of the reaction, the reaction mixture was poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. To the resulting white solid, hexane (30 mL) was added and the solution was filtered to give Compound 2 (6.90 g, 10 mmol) in a quantitative manner.

[0281]

15 $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.43 (2H, d, J = 2.4 Hz, Ar-H), 7.94 (2H, s, Ar-H), 7.33 (2H, dd, J = 2.4 Hz, 9.2 Hz, Ar-H), 6.96 (2H, d, J = 9.2 Hz, Ar-H), 5.07 (2H, d, J = 7.2 Hz, Ar-OCH₂), 4.98 (2H, d, J = 7.2 Hz, Ar-OCH₂), 3.20 (6H, s, OCH₃).

[0282]

[0283]



[0284]

In an argon atmosphere, a 1.40M *tert*-butyllithium solution (1.93 mL, 2.7 mmol) was added dropwise to a tetrahydrofuran solution (10 mL) of Compound 2 (0.207 g, 0.30 mmol) at -78°C, and the mixture was stirred for 15 minutes. Subsequently, a corresponding trialkylchlorosilane (1.80 mmol) was added at -78°C, and the reaction mixture was allowed to warm to room temperature and was then stirred for 4 hours. After completion of the reaction, the reaction mixture was poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. The resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compounds 3a through 3e in yields of 60 to 85%.

[0285]

Chemical data for the products of Examples 2 through 6 are shown below.

[0286]

<Product of Example 2 (Compound 3a)>

(R)-1,1'-bi-{4,6-bis(trimethylsilyl)-2-methoxymethoxy}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.29 (2H, s, Ar-H), 7.72 (2H, s, Ar-H), 7.31 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.16 (2H, d, J = 8.4 Hz, Ar-H), 5.03 (2H, d, J = 6.4 Hz, Ar-OCH₂), 4.95 (2H, d, J = 6.4 Hz, Ar-OCH₂), 3.15 (6H, s, OCH₃), 0.55 (18H, s, SiCH₃), 0.27 (18 H, s, SiCH₃).

[0287]

10 <Product of Example 3 (Compound 3b)>

(R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-methoxymethoxy}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.24 (2H, s, Ar-H), 7.67 (2H, s, Ar-H), 7.31 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.19 (2H, d, J = 8.4 Hz, Ar-H), 5.04 (2H, d, J = 6.4 Hz, Ar-OCH₂), 4.91 (2H, d, J = 6.4 Hz, Ar-OCH₂), 2.97 (6H, s, OCH₃), 1.40-0.80 (60H, m, SiCH₂CH₃).

[0288]

<Product of Example 4 (Compound 3c)>

(R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-methoxymethoxy}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.25 (2H, s, Ar-H), 7.64 (2H, s, Ar-H), 7.31 (2H, d, J = 8.4 Hz, Ar-H), 7.21 (2H, d, J = 8.4 Hz, Ar-H), 5.04 (2H, d, J = 6.4 Hz, Ar-OCH₂), 4.89 (2H, d, J = 6.4 Hz, Ar-OCH₂), 2.89 (6H, s, OCH₃), 1.39-0.80 (108H, m, SiCH₂CH₂CH₂CH₃).

25 [0289]

<Product of Example 5 (Compound 3d)>

(R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-methoxymethoxy}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.05 (2H, s, Ar-H), 7.33 (2H, s, Ar-H), 7.59-7.28 (22H, m, Ar-H), 7.10 (2H, 5 d, J = 8.4 Hz, Ar-H), 5.97 (2H, d, J = 6.4 Hz, Ar-OCH₂), 4.88 (2H, d, J = 6.4 Hz, Ar-OCH₂), 3.04 (6H, s, OCH₃), 0.67 (12H, s, SiCH₃), 0.41 (12H, s, SiCH₃).

[0290]

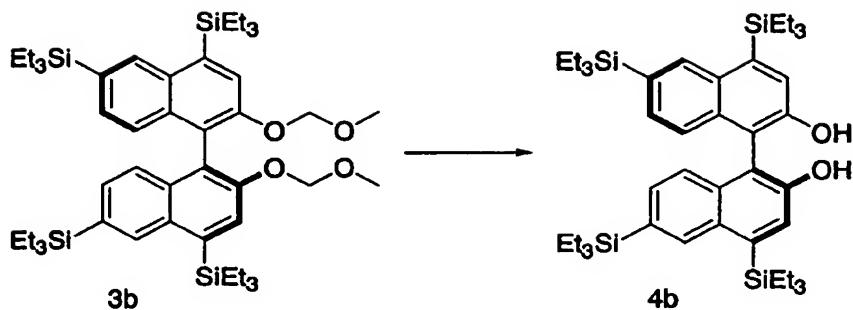
<Product of Example 6 (Compound 3e)>

(R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-methoxymethoxy}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.27 (2H, s, Ar-H), 7.70 (2H, s, Ar-H), 7.30 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.16 (2H, d, J = 8.4 Hz, Ar-H), 5.03 (2H, d, J = 6.4 Hz, Ar-OCH₂), 4.93 (2H, d, J = 6.4 Hz, Ar-OCH₂), 3.09 (6H, s, OCH₃), 1.45-0.72 (68H, m, SiC₈H₁₇), 0.48 (12H, s, SiCH₃), 0.27 (12H, s, SiCH₃).

[0291]

Example 7 Synthesis of (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-hydroxy}naphthyl (4b)

20 [0292]



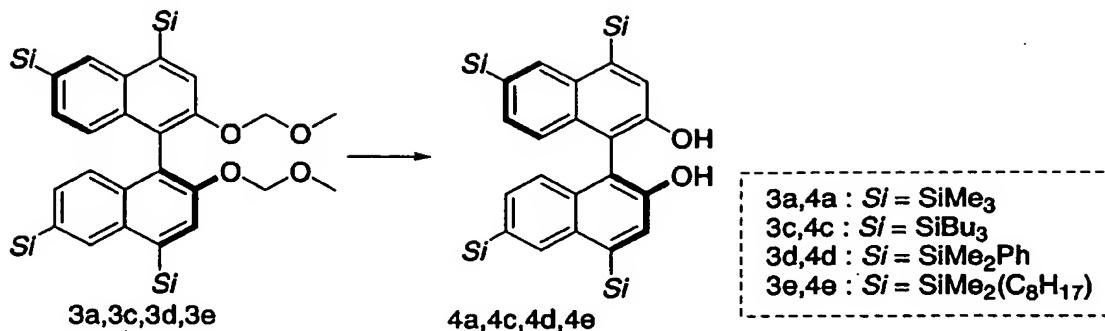
[0293]

p-toluenesulfonic acid monohydrate (0.114g, 0.60 mmol) was added to Compound 3b (0.30 mmol) in dichloromethane (10 mL) and methanol (10 mL) at room temperature, and the mixture was stirred at 50°C for 24 hours. After completion of the reaction, the reaction mixture was poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure to give Compound 4b in a quantitative yield.

[0294]

¹H-NMR (400 MHz, CDCl₃) δ 8.28 (2H, s, Ar-H), 7.54 (2H, s, Ar-H), 7.39 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.29 (2H, d, J = 8.4 Hz, Ar-H), 4.99 (2H, s, OH), 1.11-0.80 (60H, m, SiCH₂CH₃). Examples 8 through 11 Synthesis of (R)-1,1'-bi-{4,6-bis(trialkylsilyl)-2-hydroxy}naphthyls (4a, 4c, 4d, and 4e)

[0295]



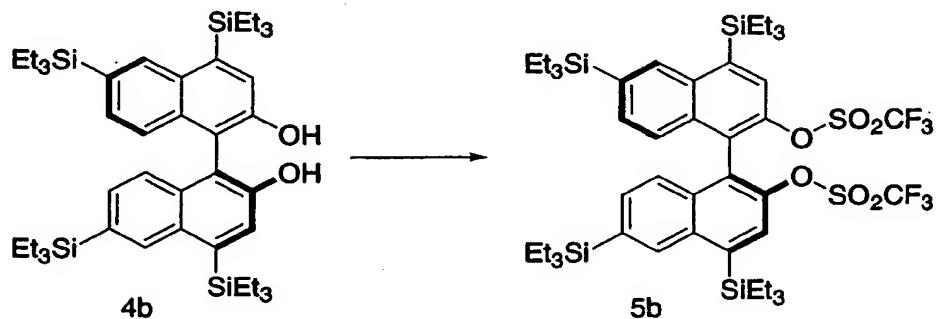
[0296]

To obtain Compounds 4a, 4c, 4d, and 4e in quantitative yields, the same procedure was followed as in Example 7, 5 except that Compound 3a, 3c, 3d, or 3e was used as the starting material in place of Compound 3b.

[0297]

Example 12 Synthesis of (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-trifluoromethanesulfonyl}naphthyl (5b)

10 [0298]



[0299]

In an argon atmosphere, triethylamine (11.1 mmol) was added to a dichloromethane solution (25 mL) of Compound 4b (3.70 mmol), and the mixture was cooled to -78°C.

Trifluoromethanesulfonic acid anhydride (11.1 mmol) was added dropwise, and the mixture was allowed to warm to room temperature, followed by stirring for 1 hour. Subsequently, the reaction mixture was poured into a saturated aqueous solution of ammonium chloride and the solution was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. After concentration, the resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compound 5b in a quantitative yield.

[0300]

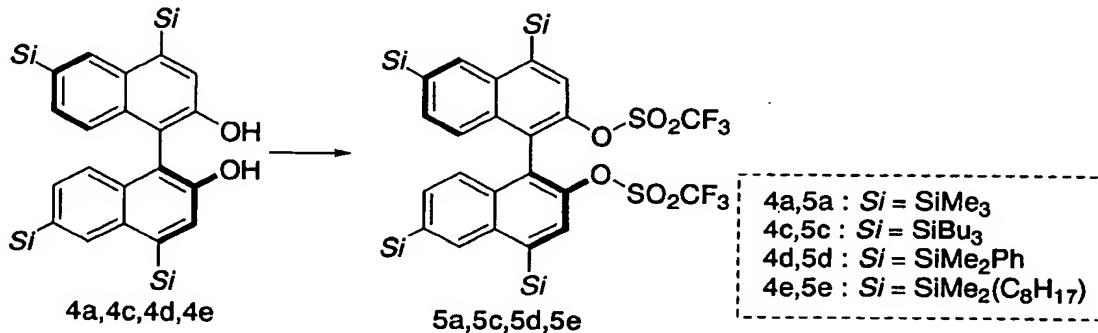
¹H-NMR (400MHz, CDCl₃) σ 8.35 (2H, s, Ar-H), 7.71 (2H, s, Ar-H), 7.47 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.30 (2H, d, J = 8.4 Hz, Ar-H), 1.11-0.85 (60H, m, SiCH₂CH₃).

Examples 13 through 16

Synthesis of (R)-1,1'-bi-{4,6-

bis(trialkylsilyl)-2-trifluoromethanesulfonyl}naphthyls (5a, 5c, 5d, and 5e)

[0301]

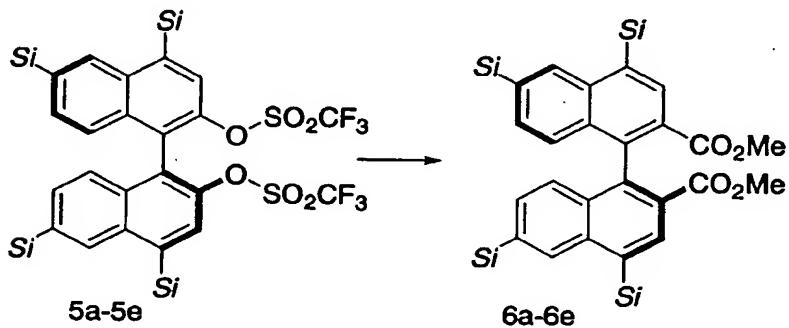


[0302]

To obtain Compounds 5a, 5c, 5d, and 5e in quantitative yields, the same procedure was followed as in Example 12, except that Compound 4a, 4c, 4d, or 4e was used as the starting material in place of Compound 4b.

[0303]

[0304]



5a,6a : $Si = SiMe_3$
 5b,6b : $Si = SiEt_3$
 5c,6c : $Si = SiBu_3$
 5d,6d : $Si = SiMe_2Ph$
 5e,6e : $Si = SiMe_2(C_8H_{17})$

10

[0305]

In an argon atmosphere, iPr₂NEt (0.51 mL), MeOH (1.0 mL) and DMSO (2.0 mL) were added to a mixture containing one of Compounds 5a through 5e (0.70 mmol), Pd(OAc)₂ (15 mol%), and 15 dppp (16.5 mol%). While the reaction vessel was pressurized to 15 atm under CO atmosphere, the mixture was stirred at 100°C for 24 hours. Subsequently, the reaction mixture was poured into water and the solution was extracted with ethyl acetate. The extract was dried over anhydrous sodium sulfate and was 20 concentrated under reduced pressure. After concentration, the

resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compounds 6a through 6e in yields of 58 to 80%.

5 [0306]

Chemical data for the products of Examples 17 through 21 are shown below.

[0307]

<Product of Example 17 (Compound 6a)>

10 (R)-1,1'-bi-{4,6-bis(trimethylsilyl)-2-methoxycarbonyl}naphthyl: $^1\text{H-NMR}$ (400MHz, CDCl_3) σ 8.34 (2H, s, Ar-H), 8.33 (2H, s, Ar-H), 7.31 (2H, d, J = 8.4 Hz, Ar-H), 7.03 (2H, d, J = 8.4 Hz, Ar-H), 3.53 (6H, s, CO_2CH_3), 0.57 (18H, s, SiCH_3), 0.30 (18H, s, SiCH_3).

15 [0308]

<Product of Example 18 (Compound 6b)>

(R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-methoxycarbonyl}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.31 (2H, s, Ar-H), 8.28 (2H, s, Ar-H), 7.32 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.11 (2H, d, J = 8.4 Hz, Ar-H), 3.32 (6H, s, CO_2CH_3), 1.12-0.82 (60H, m, SiCH_2CH_3).

[0309]

<Product of Example 19 (Compound 6c)>

(R)-1,1'-bi-{4,6-bis(tributylsilyl)-2-methoxycarbonyl}naphthyl: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.32 (2H, s,

Ar-H), 8.27 (2H, s, Ar-H), 7.32 (2H, d, J = 8.4 Hz, Ar-H),
7.13 (2H, d, J = 8.4 Hz, Ar-H), 3.27 (6H, s, CO₂CH₃), 1.38-0.81
(108H, m, SiCH₂CH₂CH₂CH₃).

[0310]

5 <Product of Example 20 (Compound 6d)>

(R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)-2-methoxycarbonyl}naphthyl: ¹H-NMR (400 MHz, CDCl₃) σ 8.40 (2H, s, Ar-H), 8.11 (2H, s, Ar-H), 7.52 (2H, d, J = 8.4 Hz, Ar-H), 7.38-7.22 (20H, m, Ar-H), 7.10 (2H, d, J = 8.4 Hz, Ar-H), 3.49 (6H, s, CO₂CH₃), 0.70 (12H, s, SiCH₃), 0.37 (12H, s, SiCH₃).

[0311]

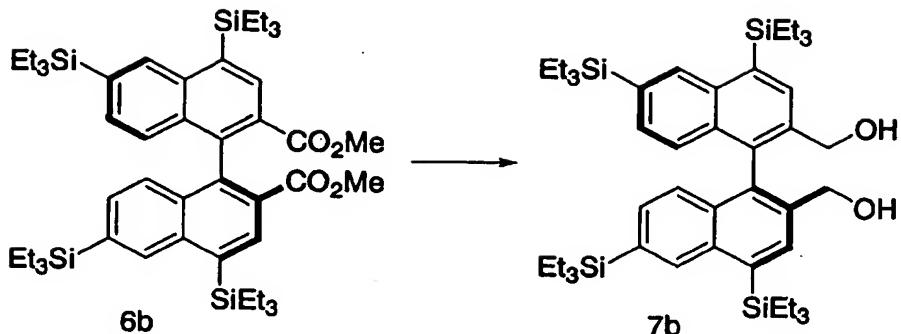
<Product of Example 21 (Compound 6e)>

(R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)-2-methoxycarbonyl}naphthyl: ¹H-NMR (400MHz, CDCl₃) σ 8.33 (2H, s, Ar-H), 8.30 (2H, s, Ar-H), 7.29 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.04 (2H, d, J = 8.4 Hz, Ar-H), 3.47 (6H, s, CO₂CH₃), 1.43-0.75 (68H, m, SiC₈H₁₇), 0.55 (12H, s, SiCH₃), 0.28 (12H, s, SiCH₃).

[0312]

20 Example 22 Synthesis of (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-hydroxymethyl}naphthyl (7b)

[0313]



[0314]

In an argon atmosphere, Compound 6b (0.44 mmol) was added to a tetrahydrofuran solution of LiAlH₄ (1.30 mmol) at 0°C, and 5 the mixture was stirred for 1 hour. Subsequently, the reaction mixture was deactivated by sequentially adding MeOH and a saturated aqueous solution of ammonium chloride and the solution was extracted with diethylether. The extract was dried over anhydrous sodium sulfate and was concentrated under 10 reduced pressure. The resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compound 7b in a quantitative yield.

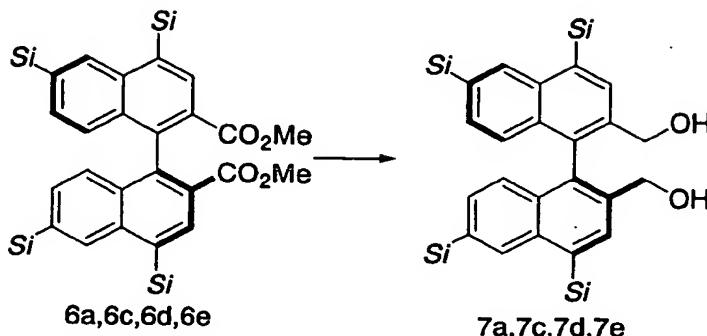
[0315]

15 ¹H-NMR (400 MHz, CDCl₃) σ 8.31 (2H, s, Ar-H), 7.84 (2H, s, Ar-H), 7.32 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.05 (2H, d, J = 8.4 Hz, Ar-H), 4.42 (2H, d, J = 11.6 Hz, ArCH₂), 4.16 (2H, d, J = 11.6 Hz, ArCH₂), 2.86 (2H, br s, OH), 1.13-0.80 (60H, m, SiCH₂CH₃).

20 [0316]

Examples 23 through 26 Synthesis of (R)-1,1'-bi-{4,6-bis(trialkylsilyl)-2-hydroxymethyl}naphthyls (7a, 7c, 7d, and 7e)

[0317]



6a,7a : Si = SiMe₃
6c,7c : Si = SiBu₃
6d,7d : Si = SiMe₂Ph
6e,7e : Si = SiMe₂(C₈H₁₇)

5

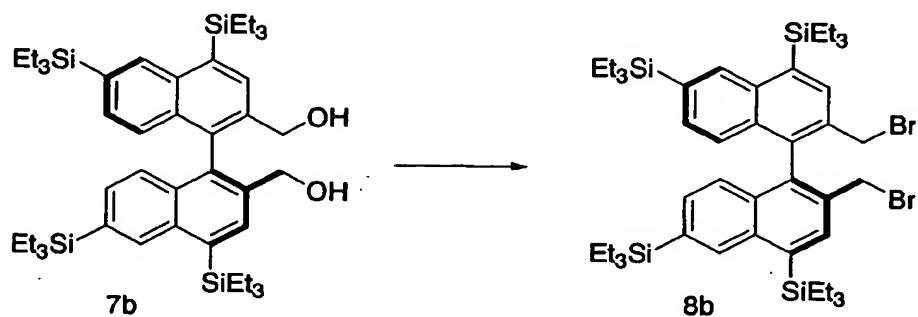
[0318]

To obtain Compounds 7a, 7c, 7d, and 7e in quantitative yields, the same procedure was followed as in Example 22, except that Compound 6a, 6c, 6d, or 6e was used as the starting material in place of Compound 6b.

[0319]

Example 27 Synthesis of (R)-1,1'-bi-{4,6-bis(triethylsilyl)-2-bromomethyl}naphthyl (8b)

[0320]



15

[0321]

Triphenylphosphine (0.315 g, 1.2 mmol) and carbon tetrabromide (0.398 g, 1.2 mmol) were added to a tetrahydrofuran solution (10 mL) of Compound 7b (0.20 mmol), and the mixture was stirred at room temperature for 4 hours.

5 After completion of the reaction, the reaction mixture was poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. After concentration, the residue was subjected to a silica gel 10 column chromatography and was eluted with a hexane solvent to give Compound 8b in a quantitative yield.

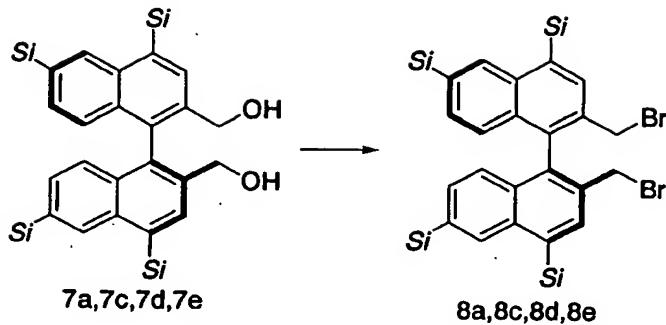
[0322]

¹H-NMR (400 MHz, CDCl₃) δ 8.28 (2H, s, Ar-H), 7.87 (2H, s, Ar-H), 7.34 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.06 (2H, d, J = 15 8.4 Hz, Ar-H), 4.24 (4H, s, ArCH₂), 1.13-0.80 (60H, m, SiCH₂CH₃).

[0323]

Examples 28 through 31 Synthesis of (R)-1,1'-bi-{4,6-bis(trialkylsilyl)-2-bromomethyl}naphthyls (8a, 8c, 8d, and 20 8e)

[0324]



7a,8a : Si = SiMe₃
 7c,8c : Si = SiBu₃
 7d,8d : Si = SiMe₂Ph
 7e,8e : Si = SiMe₂(C₈H₁₇)

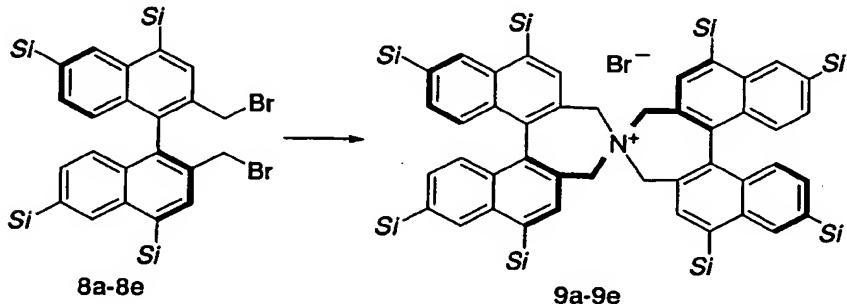
[0325]

To obtain Compounds 8a, 8c, 8d, and 8e in quantitative yields, the same procedure was followed as in Example 27, except that Compound 7a, 7c, 7d, or 7e was used as the starting material in place of Compound 7b.

[0326]

Examples 32 through 36 Synthesis of spiro-bis[{{(R)-1,1'-bi-4,6-bis(trimethylsilyl)naphthyl}}2,2'-dimethyl]ammonium bromides (9a through 9e)

[0327]



8a,9a : Si = SiMe₃
 8b,9b : Si = SiEt₃
 8c,9c : Si = SiBu₃
 8d,9d : Si = SiMe₂Ph
 8e,9e : Si = SiMe₂(C₈H₁₇)

[0328]

A 28% aqueous ammonia (0.77 mL, 12.6 mmol) and acetonitrile (5 mL) were added to one of Compounds 8a through 8e (3.15 mmol). The reaction vessel was sealed and the mixture

was stirred for 24 hours while being refluxed. Subsequently, the reaction mixture was poured into water and the solution was extracted with dichloromethane. The extract was dried over anhydrous sodium sulfate and was concentrated under reduced 5 pressure. After concentration, the resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of dichloromethane/methanol to give Compounds 9a through 9e in yields of 25 to 65%.

[0329]

10 Chemical data for the products of Examples 32 through 36 are shown below.

[0330]

<Product of Example 32 (Compound 9a)>

15 Spiro-bis[{(R)-1,1'-bi-{4,6-bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide: $^1\text{H-NMR}$ (400MHz, CDCl_3) σ 8.50 (4H, s, Ar-H), 7.80 (4H, s, Ar-H), 7.44 (4H, d, J = 8.8 Hz, Ar-H), 7.30 (4H, d, J = 8.8 Hz, Ar-H), 4.46 (4H, d, J = 14.0 Hz, Ar CH_2), 4.10 (4H, d, J = 14.0 Hz, Ar CH_2), 0.73 (36H, s, Si CH_3), 0.36 (36H, s, Si CH_3).

20 [0331]

<Product of Example 33 (Compound 9b)>

25 Spiro-bis[{(R)-1,1'-bi-{4,6-bis(trimethylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide: $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.48 (4H, s, Ar-H), 7.91 (4H, s, Ar-H), 7.43 (4H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.25 (4H, d, J = 8.4 Hz, Ar-H), 4.38 (4H, d, J = 13.2

Hz, ArCH₂), 4.08 (4H, d, J = 13.2 Hz, ArCH₂), 1.32-0.85 (120H, m, SiCH₂CH₃).

[0332]

<Product of Example 34 (Compound 9c)>

5 Spiro-bis[{(R)-1,1'-bi-{4,6-bis(tributylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide: ¹H-NMR (400 MHz, CDCl₃) σ 8.47 (4H, s, Ar-H), 7.85 (4H, s, Ar-H), 7.36 (4H, d, J = 8.4 Hz, Ar-H), 7.13 (4H, d, J = 8.4 Hz, Ar-H), 4.39 (4H, d, J = 13.6 Hz, ArCH₂), 4.15 (4H, d, J = 13.6 Hz, ArCH₂), 1.43-0.85 (108H, m, 10 SiCH₂CH₂CH₂CH₃).

[0333]

<Product of Example 35 (Compound 9d)>

15 Spiro-bis[{(R)-1,1'-bi-{4,6-bis(dimethylphenylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide: ¹H-NMR (400 MHz, CDCl₃) σ 8.23 (4H, s, Ar-H), 8.18 (4H, s, Ar-H), 7.57-7.21 (48H, m, Ar-H), 4.61 (4H, d, J = 13.6 Hz, ArCH₂), 4.27 (4H, d, J = 13.6 Hz, ArCH₂), 0.81 (12H, s, SiCH₃), 0.74 (12H, s, SiCH₃), 0.39 (12H, s, SiCH₃), 0.38 (12H, s, SiCH₃).

20 [0334]

<Product of Example 36 (Compound 9e)>

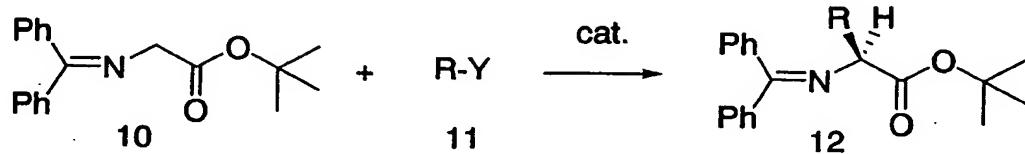
25 Spiro-bis[{(R)-1,1'-bi-{4,6-bis(dimethyloctylsilyl)naphthyl}}-2,2'-dimethyl]ammonium bromide: ¹H-NMR (400 MHz, CDCl₃) σ 8.47 (4H, s, Ar-H), 7.96 (4H, s, Ar-H), 7.41 (4H, d, J = 8.4 Hz, Ar-H), 7.26 (4H, d, J = 8.4 Hz, Ar-H), 4.43 (4H, d, J = 13.2

Hz, ArCH₂), 4.11 (4H, d, J = 13.2 Hz, ArCH₂), 1.53-0.80 (136H, m, SiC₆H₁₇), 0.73 (12H, s, SiCH₃), 0.70 (12H, s, SiCH₃), 0.35 (12H, s, SiCH₃), 0.34 (12H, s, SiCH₃).

[0335]

5 Examples 37 through 52 Asymmetric alkylation using Compounds (9a) through (9e) as an optically active phase-transfer catalyst

[0336]



10 [0337]

At 0°C, Compound 11 (0.6 mmol) of the formula (13) shown as R-Y in Table 1 was added to a mixture of Compound 10 of the formula (12) (0.5 mmol), a phase-transfer catalyst (one of Compound (9a), Compound (9b), Compound (9c), Compound (9d), and Compound (9e)) (0.05 mmol), toluene (3.3 mL), and a 50% aqueous solution of potassium hydroxide (1.0 mL). The mixture was stirred at the same temperature and was poured into water. The solution was extracted with ether and the extract was washed with saturated brine, followed by drying over sodium sulfate and concentration under reduced pressure. The resulting residue was subjected to a silica gel column chromatography to give an alkylated compound 12 of the formula (14). The results obtained for different phase-transfer

catalysts and different alkylating agents were collectively shown in Table 1.

[0338]

The optical purity of the reaction products was 5 determined according to the technique described in *J. Am. Chem. Soc.* 1999, Vol. 121, No. 27, 6519-6520.

[0339]

Table 1

Examples	R - Y	Cat.	Time [h]	Yield [%]	Ee [%]
3 7	PhCH ₂ Br	9 e	1 7 2	9 6	9 9
3 8	"	9 d	2 6	9 8	9 8
3 9	"	9 c	5 0	9 2	9 9
4 0	"	9 b	6	9 7	9 7
4 1	"	9 a	9 6	6 0	9 2
4 2	MeI	9 e	1 4	9 2	9 3
4 3	"	9 d	1 6	9 2	9 2
4 4	"	9 c	1 0	9 3	8 8
4 5	"	9 b	2 2	9 0	8 9
4 6	"	9 a	1 0	9 2	9 2
4 7	CH ₂ =CHCH ₂ Br	9 e	9 6	9 8	9 8
4 8	HC≡CCH ₂ Br	9 e	3 2	9 6	9 9
4 9	EtI	9 e	1 0	8 7	9 8
5 0	HexI	9 e	1 0	8 1	9 7
5 1	iPr-I	9 e	1 5	7 0	9 5
5 2	cPent-I	9 e	1 5	7 5	9 6

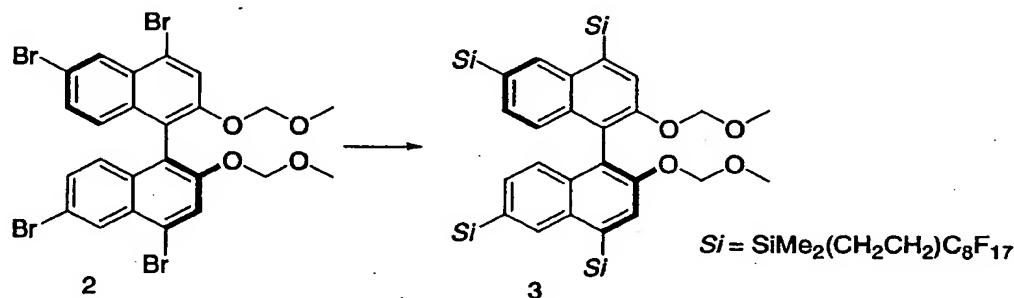
[0340]

The present invention will now be described in further detail with reference to examples of fluorine-containing, optically active quaternary ammonium salts represented by the 5 formula (1b). These examples, however, are provided by way of example only and are not intended to limit the scope of the invention in any way.

[0341]

Example 53 Synthesis of (R)-1,1'-bi-{4,6-bis(2-
10 perfluoroctylethyldimethylsilyl)-2-methoxymethoxy}naphthyl
(3)

[0342]



[0343]

15 In an argon atmosphere, a 1.40M *tert*-butyllithium solution (1.93 mL, 2.7 mmol) was added dropwise to a tetrahydrofuran solution (10 mL) of Compound 2 (0.207 g, 0.30 mol) at -78°C and the mixture was stirred for 15 minutes. Subsequently, dimethyl(perfluoroctyl)ethylchlorosilane (1.80 20 mmol) was added at -78°C, and the reaction mixture was allowed to warm to room temperature and was then stirred for 4 hours.

After completion of the reaction, the reaction mixture was poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. After 5 concentration, the residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compound 3 in a yield of 85%. Chemical data for the product are shown below.

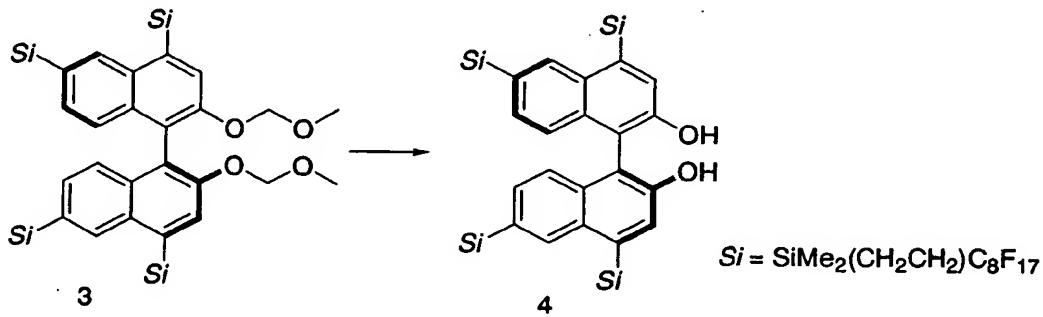
[0344]

10 $^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.21 (2H, s, Ar-H), 7.74 (2H, s, Ar-H), 7.30 (2H, d, $J = 8.4$ Hz, Ar-H), 7.18 (2H, d, $J = 8.4$ Hz, Ar-H), 5.07 (2H, d, $J = 6.8$ Hz, Ar-OCH₂), 4.95 (2H, d, $J = 6.8$ Hz, Ar-OCH₂), 3.10 (6H, s, OCH₃), 2.16-1.95 (8H, m, CH₂CF₂), 1.32-1.27 (4H, m, SiCH₂), 1.02-0.98 (4H, m, SiCH₂), 0.61 (12H, 15 s, SiCH₃), 0.37 (6H, s, SiCH₃), 0.36 (6H, s, SiCH₃).

[0345]

Example 54 Synthesis of (R)-1,1'-bi-{4,6-bis(2-perfluorooctylethyldimethylsilyl)-2-hydroxy}naphthyl (4)

[0346]



20

[0347]

p-toluenesulfonic acid monohydrate (0.114 g, 0.60 mmol) was added to Compound 3 (0.30 mmol) in dichloromethane (10 mL) and methanol (10 mL) at room temperature, and the mixture was stirred at 50°C for 24 hours. After completion of the reaction, 5 the reaction mixture was poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure to give Compound 4 in a quantitative yield. The chemical data for the product are shown below.

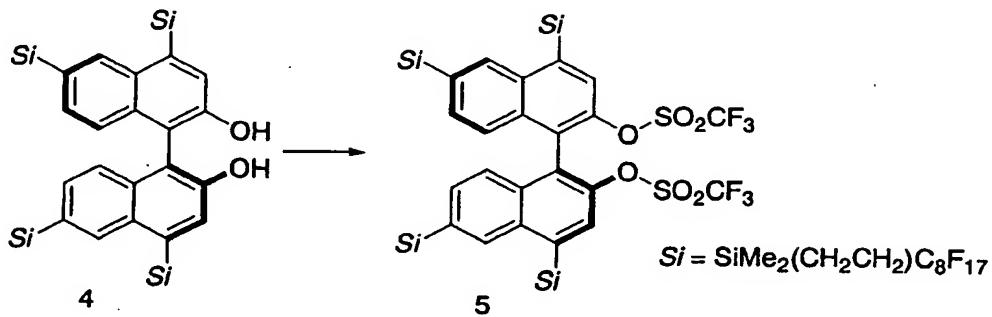
10 [0348]

$^1\text{H-NMR}$ (400 MHz, CDCl_3) δ 8.23 (2H, s, Ar-H), 7.58 (2H, s, Ar-H), 7.39 (2H, d, J = 8.4 Hz, Ar-H), 7.20 (2H, d, J = 8.4 Hz, Ar-H), 5.01 (2H, s, OH), 2.13-1.97 (8H, m, CH_2CF_2), 1.33-1.28 (4H, m, SiCH_2), 1.04-0.99 (4H, m, SiCH_2), 0.61 (12H, s, SiCH_3), 15 0.37 (12H, s, SiCH_3).

[0349]

Example 55 Synthesis of (R)-1,1'-bi-{4,6-bis(2-perfluoroctylethyldimethylsilyl)-2-trifluoromethanesulfonyl}naphthyl (5)

20 [0350]



[0351]

In an argon atmosphere, triethylamine (11.1 mmol) was added to a dichloromethane solution (25 mL) of Compound 4 (3.70 mmol), and the mixture was cooled to -78°C.

5 Trifluoromethanesulfonic acid anhydride (11.1 mmol) was added dropwise, and the mixture was allowed to warm to room temperature, followed by stirring for 1 hour. Subsequently, the reaction mixture was poured into a saturated aqueous solution of ammonium chloride and the solution was extracted 10 with dichloromethane. The dichloromethane solution was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. After concentration, the resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compound 5 15 in a quantitative yield. Chemical data for the product are shown below.

[0352]

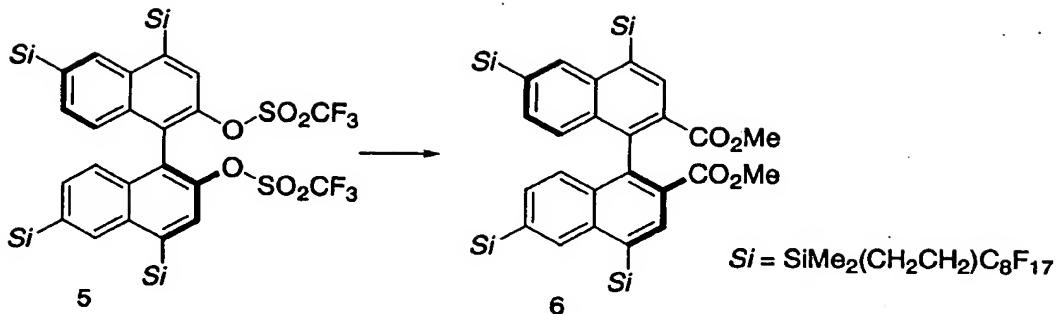
¹H-NMR (400 MHz, CDCl₃) δ 8.33 (2H, s, Ar-H), 7.72 (2H, s, Ar-H), 7.47 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.32 (2H, d, J = 20 8.4 Hz, Ar-H), 2.05-1.87 (8H, m, CH₂CF₂), 1.35-1.24 (4H, m, SiCH₂), 1.05-1.01 (4H, m, SiCH₂), 0.66 (6H, s, SiCH₃), 0.64 (6H, s, SiCH₃), 0.43 (6H, s, SiCH₃), 0.41 (6H, s, SiCH₃).

[0353]

Example 56 Synthesis of (R)-1,1'-bi-{4,6-bis(2-25 perfluoroctylethyldimethylsilyl)-2-methoxycarbonyl}naphthyl

(6)

[0354]



[0355]

5 In an argon atmosphere, iPr₂Net (0.51 mL), MeOH (1.0 mL), and DMSO (2.0 mL) were added to a mixture containing Compound 5 (0.70 mmol), Pd(OAc)₂ (15 mol%), and dppp (16.5 mol%). While the reaction vessel was pressurized to 15atm under CO atmosphere, the mixture was stirred at 100°C for 24 hours.

10 Subsequently, the reaction mixture was poured into water and the solution was extracted with ethyl acetate. The extract was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. After concentration, the resulting residue was subjected to a silica gel column chromatography and eluted

15 with a mixed solvent of diethylether/hexane to give Compound 6 in a yield of 70%. Chemical data for the product are shown below.

[0356]

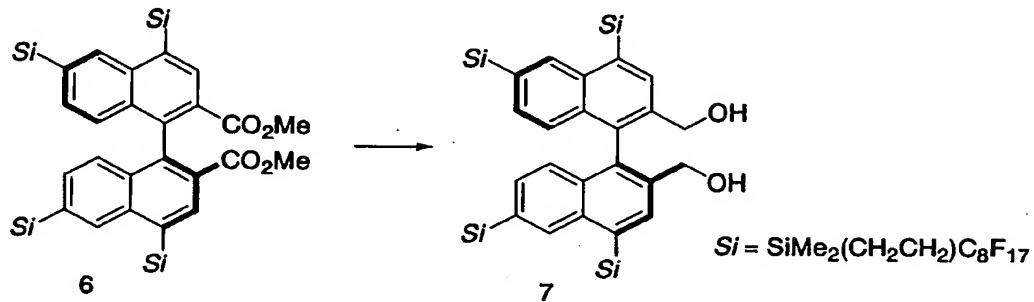
¹H-NMR (400 MHz, CDCl₃) δ 8.36 (2H, s, Ar-H), 8.29 (2H, s, Ar-H), 7.33 (2H, d, J = 8.4 Hz, Ar-H), 7.23 (2H, d, J = 8.4 Hz,

Ar-H), 3.50 (6H, s, CO₂CH₃), 2.18-1.93 (8H, m, CH₂CF₂), 1.35-1.31 (4H, m, SiCH₂), 1.04-1.00 (4H, m, SiCH₂), 0.53 (12H, s, SiCH₃), 0.38 (12H, s, SiCH₃).

[0357]

5 Example 57 Synthesis of (R)-1,1'-bi-{4,6-bis(2-perfluoroctylethyldimethylsilyl)-2-hydroxymethyl}naphthyl (7)

[0358]



10 [0359]

In an argon atmosphere, Compound 6 (0.44 mmol) was added to a tetrahydrofuran solution of LiAlH₄ (1.30 mmol) at 0°C, and the mixture was stirred for 1 hour. Subsequently, the reaction mixture was deactivated by sequentially adding MeOH and a 15 saturated aqueous solution of ammonium chloride and the solution was extracted with diethylether. The extract was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. The resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of diethylether/hexane to give Compound 7 in a quantitative yield. Chemical data for the product are shown

below.

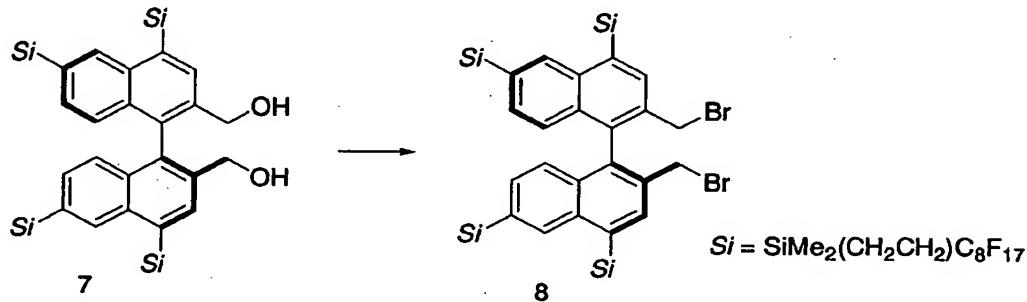
[0360]

¹H-NMR (400 MHz, CDCl₃) σ 8.27 (2H, s, Ar-H), 7.90 (2H, s, Ar-H), 7.33 (2H, d, J = 8.4 Hz, Ar-H), 7.10 (2H, d, J = 8.4 Hz, 5 Ar-H), 4.43 (2H, d, J = 11.6 Hz, ArCH₂), 4.14 (2H, d, J = 11.6 Hz, ArCH₂), 3.20 (2H, br s, OH), 2.16-1.98 (8H, m, CH₂CF₂), 1.34-1.29 (4H, m, SiCH₂), 1.06-1.01 (4H, m, SiCH₂), 0.63 (12H, s, SiCH₃), 0.37 (12H, s, SiCH₃).

[0361]

10 Example 58 Synthesis of (R)-1,1'-bi-{4,6-bis(2-perfluoroctyloxyethyl)dimethylsilyl)-2-bromomethyl}naphthyl (8)

[0362]



[0363]

15 Triphenylphosphine (0.315 g, 1.2 mmol) and carbon tetrabromide (0.398 g, 1.2 mmol) were added to a tetrahydrofuran solution (10 mL) of Compound 7 (0.20 mmol), and the mixture was stirred at room temperature for 4 hours. After completion of the reaction, the reaction mixture was 20 poured into water and was extracted with dichloromethane. The dichloromethane solution was dried over anhydrous sodium

sulfate and was concentrated under reduced pressure. After concentration, the residue was subjected to a silica gel column chromatography and was eluted with a hexane solvent to give Compound 8 in a quantitative yield. Chemical data for the product are shown below.

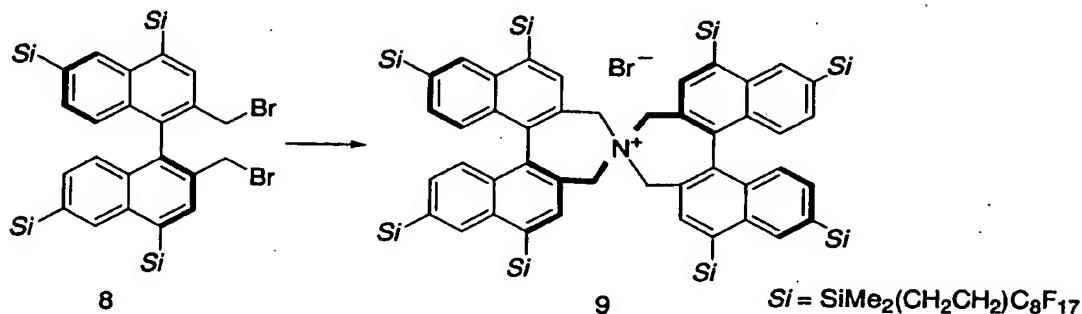
[0364]

¹H-NMR (400 MHz, CDCl₃) σ 8.25 (2H, s, Ar-H), 7.89 (2H, s, Ar-H), 7.35 (2H, dd, J = 1.2 Hz, 8.4 Hz, Ar-H), 7.09 (2H, d, J = 8.4 Hz, Ar-H), 4.23 (4H, s, ArCH₂), 2.17-1.97 (8H, m, CH₂CF₂), 1.34-1.25 (4H, m, SiCH₂), 1.04-1.00 (4H, m, SiCH₂), 0.64 (12H, s, SiCH₃), 0.38 (12H, s, SiCH₃).

[03651]

Example 59 Synthesis of Spiro-bis-{(R)-1,1'-bi-[4,6-bis(2-perfluoroctylethyldimethylsilyl)]naphthyl-2,2'-dimethyl}ammonium bromide (9)

[0366]



[0367]

A 28% aqueous ammonia (0.77 mL, 12.6 mmol) and acetonitrile (5 mL) were added to Compounds 8 (3.15 mmol). The

reaction vessel was sealed and the mixture was stirred for 24 hours while being refluxed. Subsequently, the reaction mixture was poured into water and the solution was extracted with dichloromethane. The extract was dried over anhydrous sodium sulfate and was concentrated under reduced pressure. After concentration, the resulting residue was subjected to a silica gel column chromatography and eluted with a mixed solvent of dichloromethane/methanol to give Compounds 9. Chemical data for the product are shown below.

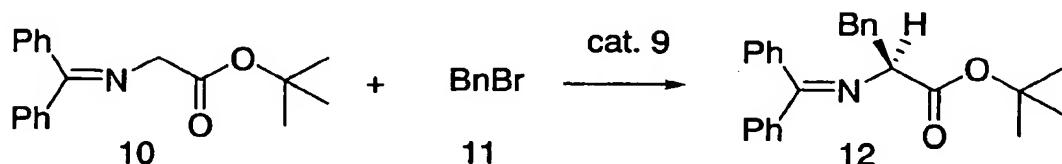
10 [0368]

$^1\text{H-NMR}$ (400 MHz, CDCl_3) σ 8.41 (4H, s, Ar-H), 8.06 (4H, s, Ar-H), 7.39 (4H, d, J = 8.4 Hz, Ar-H), 7.25 (4H, d, J = 8.4 Hz, Ar-H), 4.48 (4H, d, J = 13.6 Hz, Ar CH_2), 4.26 (4H, d, J = 13.6 Hz, Ar CH_2), 2.20-1.98 (16H, m, CH_2CF_2), 1.44-1.40 (8H, m, Si CH_2), 15 1.07-1.03 (8H, m, Si CH_2), 0.84 (12H, s, Si CH_3), 0.79 (12H, s, Si CH_3), 0.60 (12H, s, Si CH_3), 0.43 (12H, s, Si CH_3).

[0369]

Example 60 Asymmetric alkylation using Compound (9) as optically active phase-transfer catalyst, recovery and recycle 20 of the catalyst

[0370]



[0371]

At 0°C and in an argon atmosphere, benzyl bromide (11) (0.36 mmol) was added to a toluene solution (3.0 mL) of Compound (10) of the formula (12) (0.3 mmol) and Compound (9) of the formula (1) (0.009 mmol). A 50% aqueous solution of 5 potassium hydroxide (1.0 mL) was added dropwise and the mixture was vigorously stirred for 96 hours at the same temperature. Subsequently, the mixture was diluted with water (3.0 mL) and toluene (3.0 mL), and Compound (9) was extracted from the diluted solution with FC-72 (perfluorohexane) (3.0 mL x 3). The fluorous solvent was evaporated under reduced pressure and the remaining residue (quantitatively recovered for use as catalyst) was directly used in the subsequent reaction without further purification. The crude product, which was a mixed solution of toluene/water containing 10 Compound (12) as a primary component, was extracted with ether. The organic phase was washed with saturated brine, dried over sodium sulfate, and concentrated under reduced pressure. The residue was subjected to a silica gel column chromatography to give the alkylated compound 12. The results are shown in Table 15 2.

20 [0372]

Example 61

Using the catalyst recovered in Example 60, the same process was repeated in the same reaction scale, followed by 25 the same post-process. The results are also shown in Table 2.

[0373]

Example 62

Using the catalyst recovered again in Example 61, the same process was repeated in the same reaction scale, followed by the same post-process. The results are also shown in Table 2.

[0374]

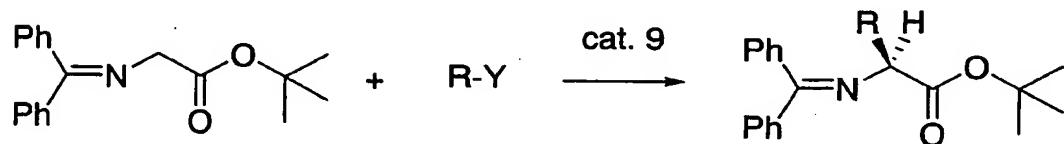
Table 2

	Catalyst 9 (Number of use)	Time (h)	Yield (%)	Optical Purity (%)
Example 60	First time	96	82	90
Example 61	Second time	96	79	92
Example 62	Third time	96	81	92

[0375]

10 Examples 63 and 64 Asymmetric alkylation using Compound (9) as a phase-transfer catalyst

[0376]



[0377]

15 Using Compound (9) as a catalyst, asymmetric alkylation was carried out in the same manner as in Example 60, except that a substrate shown as R-Y in Table 3 was used. The results are together shown in Table 3.

[0378]

Table 3

	R-Y	Time (h)	Yield (%)	Optical Purity (%)
Example 63	CH ₂ =CHCH ₂ Br	142	80	84
Example 64	HC≡CCH ₂ Br	140	81	90

[0379]

The optical purity of the reaction products was determined according to the technique described in *J. Am. Chem. Soc.* 1999, Vol. 121, No. 27, 6519-6520.